PAPERS

ON

NAVAL ARCHITECTURE

AND OTHER SUBJECTS CONNECTED WITH

NAVAL SCIENCE.

CONDUCTED BY

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DEDICATION.

TO THE

REV. JAMES INMAN, D.D.

PROFESSOR OF THE ROYAL NAVAL COLLEGE AND SCHOOL OF NAVAL ARCHITECTURE IN HIS MAJESTY'S DOCKYARD, AT PORTSMOUTH.

REV. SIR,

EVERY consideration of the circumstances connected with the publication of this work concurs in directing us to you as the person to whom it should be dedicated.

It is not too much to say, that not only much of the present knowledge of the theory of Naval Architecture in this country, but the probability of improvement in this important science, is the effect of that enlightened and decided conduct, by which you have been enabled to carry into execution the views of the Right Honourable Board of Admiralty, by the application of mathematical science to this subject, in the instruction of the students educated at the School of Naval Architecture for officers in His Majesty's Dockyards.

As Members of this Institution, we feel sentiments of sincere gratitude towards you; which are con-

nected with that respect which is paid only to kindness of heart and unsullied honour.

In expressing these sentiments, we do it with the greater confidence, having, for a considerable time, been removed without the limits of your authority; and, therefore, feeling only that wish for your favour which arises from a desire for the consideration of the learned and virtuous.

We remain,

Reverend Sir,

With the sincerest feeling of respect,

Your obedient Servants,

William Morgan,
Augustin Creuze.

Portsmouth, Jan. 1, 1826.

ADVERTISEMENT.

The state of the science of Naval Architecture is very imperfectly known in this country, arising not more from the difficulty of the subject than from the smallness of the number, and the character of the works, published on it. The abstruse manner in which it is necessary to treat many parts of the theory, and the wholly practical manner in which the construction of a ship is generally treated, render these works far better adapted for the student than for the general reader.

It is proposed, in this work, by a combination of popular and scientific papers, to give a general view of the theory and practice of Naval Architecture. The increasing interest this subject has lately excited appears to render such a work desirable.

All pretensions to the discovery of secrets in Naval Architecture will be disclaimed, as altogether inconsistent with the nature of the subject. The means of improvement in this science are the collection of facts, experiment, mathematical reasoning, and general observation; and success is to be expected only in proportion to the talent and labour devoted to it. The extent and difficulty of the subject render a very rapid advancement improbable; but there is nothing in its character which can be shown to prevent the general mode of philosophical investigation being equally applicable to this as

to other sciences; and it is reasonably to be expected, that, by equal attention to it, it will advance certainly, though slowly, to the same degree of excellency. While the conductors of this work believe mathematics to be so closely connected with its improvement, that many of its branches cannot be understood without it, they yet consider that the judicious opinion of experienced men, however unconnected with scientific reasoning, is to be received with the greatest respect, as tending to enlarge our knowledge, and direct future investigation in this science.

It will be the object of this work to collect all the information that can be obtained on Naval Architecture, and other subjects connected with Naval Science. It will relate particularly to the Design of our Ships, their Construction, the Nature of the Materials of which they are built, and the Direction of them at sea. The matter of this work will be composed of Original Papers, translations, and Extracts from works on Naval Science, Critical Remarks, and Correspondence.

It is considered that, by having a work wholly devoted to this subject, much useful matter will be obtained, which would otherwise remain unpublished; particularly, it is hoped, the observations of naval officers, by a combination of whose valuable experience, with the theoretical knowledge of the naval architect, much advantage to this science may be expected.

The conductors of this work have been promised the support of several gentlemen of considerable attainments in the theoretical and practical parts of this science.

Should the circulation of this work be such as to render a more frequent appearance of the Numbers desirable, they will be published quarterly instead of half-yearly.

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PAPERS

ON

NAVAL ARCHITECTURE.

&c.

ART. I.—*Introductory Remarks on the State of Naval Architecture.*

AMIDST the numerous scientific improvements that have contributed to the convenience, and extended the power of man, the slow progress of Naval Architecture is frequently spoken of with much regret. This science exceeds perhaps in extent and difficulty many others; yet an inquiry into the labours of those who have directed their attention to it, enables us to perceive that their investigations have been attended with considerable success: many difficulties having been removed, and many important discoveries having been made in the construction of ships.

Its improvement, however, has not had to contend only with the natural difficulties of the subject, but has frequently been impeded by objections, which, in some instances, may have produced very considerable effects. It has been said, that while our ships have been so generally successful in engagements with the enemy, they can need no alteration. This consideration may have arisen from not making a proper distinction between the qualities of our ships and the characters of our sailors. The extraordinary and brilliant success of our navy during the last war, was owing altogether to the ability of our naval officers, and the intrepidity of British seamen. To the superiority of our ships this success can never with propriety be attributed; as was fully confirmed by the accounts given of their qualities, by many officers of distinguished merit. The question appears rather to be, whether their defects did

not, in some instances, render the courage and abilities of our sailors unavailing.

Among some who even wish for the improvement of this science, there is an objection, that *mathematical* knowledge cannot be advantageously applied to it. This may arise from not considering naval architecture in the same philosophical manner as other scientific subjects. The supposition that the form of a ship's body may be at once ascertained by the solution of a mathematical problem, may lead to such an opinion. There is, however, nothing in the nature of the subject which can be shown to prevent the application of mathematics to many of its branches. Many of the properties of ships, in common with all other floating bodies, are subject to established laws, certain in their application, and capable of correct measurement. For instance, the manner in which *any body* of less specific gravity than the fluid will float, as well as the angle to which it will incline by a given force, are perfectly within the limits of mathematical demonstration. The application of this principle to the stability of a ship, is simple and certain. Many other properties of a ship are equally capable of being mathematically determined. Some branches of naval architecture are dependent on experiments, particularly those connected with the resistance of fluids; but to render these experiments practically beneficial to the science, they must be subjected to mathematical generalization.

While others admit that mathematical knowledge may be advantageously applied to the *theory* of naval architecture, they think it totally unnecessary to the *practical* part. They say that our ships are better built than those of other nations, and, therefore, that any alteration in them is needless. That our ships are generally stronger than those of other nations is certainly true; but this by no means implies that they are arrived at their greatest possible excellence. The mechanical construction of a ship must be considered exactly in the same manner as of any other machine. Considering strength as the desideratum, that machine is the most nearly perfect, in this respect, that has the strength in all parts proportional to the strain. On this principle, whatever timber is employed in a ship, not agreeable to such required proportion, is incorrect;

if the quantity be too small, by endangering the ship in a greater or less degree, according to the deficiency and its situation; and if too great, by adding unnecessary weight, and increasing the expense. If the required strength of any part may be given by a different mechanical arrangement of the materials, reducing the quantity, such a disposition would be certainly beneficial. To determine this is entirely the department of mathematical science.

But there is a more enlarged view of naval architecture, in which it ought to be considered. Mathematics is not the only science that can contribute to its progress: whatever increases our acquaintance with the forms of ships, the nature of the element in which they move, the force by which they are impelled therein, or the nature and properties of any of the materials of which they are built, conduces to the improvement of this science.

The nature of the subject does not admit of discoveries being made to determine the true forms of ships by any process universally applicable. Mechanical means of constructing curves have frequently been given by writers on the subject; but they have never been shown to possess properties conducive to any particular qualities of ships, which can be determined only by experiment and calculation.

It has been generally admitted, that the knowledge of the theory of naval architecture has been less in England than in many other parts of Europe. Ships have, consequently, been built agreeably to the forms of some of the ships we had taken. Danish and French ships were favourite models for our imitation; and there is no doubt that our navy was much improved by the introduction of these new forms. Instances, however, not unfrequently occurred, in which ships built agreeably to the forms of these models, did not fully answer the expectation raised of them. This might proceed, in some cases, from altering the size proportionally, so as to build ships of similar but not equal dimensions; but it might generally arise from not being acquainted with the detail of the circumstances connected with the design, and the dependence of the different properties on each other in producing the general good effect; so that by the alteration of some of the elements of the con-

struction, either some of the dimensions, the quantity or specific gravity of the materials, or the arrangements of some of the weights, the excellency of the design, to say the least, might be greatly diminished.

The state of any science may generally be ascertained by an examination of the works written on the subject. To become, in this manner, acquainted with the state of naval architecture in England, is much easier than in some other countries, from the smallness of the number of the books that have any claim to science. Theoretical works have been very rare: Atwood's papers in the philosophical transactions of 1796 and 1798, on the stability of floating bodies, with its application to ships, are almost the only theoretical works written in English on the subject. Works of mere empyricism can mislead but few, as the expense of experiments in the science of building ships, prevents ignorant speculators from rendering their folly more evident. Several works on the practical part of the subject have been written, but none which can be properly characterised as scientific. The works of Sunderland, Mungo Murray, Stalkart, Steel, Fincham, and the Shipwright's Repository, deserve the most attention; those of Steel are by far the most useful to a practical builder. The collection of papers on naval architecture, first published on the covers of the European Magazine, contains some valuable papers amongst a medley of curious statements of dock-yard abuses, projects practicable and impracticable, and theoretical opinions devoid of all science.

The works of Foreign authors are much more numerous: the French, Swedish, Spanish, and Dutch, have published valuable works both on the theory and practice of naval architecture. Most of them may be found in French, into which translations are generally made of every thing valuable in this science. The names of Euler, Bouguer, Don George Juan, Romme, d'Alembert, Chapman, Duhamel, Forfait, and Clairbois, are particularly distinguished amongst those to whom naval architecture is most indebted. In some instances it must be admitted, that their theories are more beautiful than useful; but this applies but to a very small part of these works, which generally contain matter as useful in practice, as pro-

found in investigation, extensive in research, and elegant in demonstration. Most of the properties of a ship are investigated in them, and the general principles that govern them determined. We may occasionally feel regret either that the authors were not more acquainted with the practice of the subject, or that their mathematical knowledge was too confined; yet, in some of their works, we see every thing necessary to conduct its investigation with success; and in all, something that may extend the knowledge of the science. While we lament that Euler was not more acquainted with the philosophy of naval architecture, and frequently substituted hypothesis where experiment and fair induction were necessary, we cannot read his elegant theories without admiring and profiting by the facility of his application of mathematical analysis to many of its branches. On the other hand, when we see that Chapman tried to subject the results of his great experience and judgment to mathematical investigation, we do not treat his results with disregard, because, while he knew their truth from experience, he in some instances wrested mathematical analysis to their support.

While various talents have contributed in different ways to the advancement of naval architecture, and perhaps few persons, if any, have directed their attention to it without some success, it is to those few who have combined experimental and theoretical knowledge that this science is particularly indebted.

The principal works of these authors, that have been translated into English, are Euler's '*Theorie complette de la Construction et de la Manœuvre des Vaisseaux*,' and Chapman's '*Tractat om Skepps-Byggeriet*:' the former by Colonel Watson, and the latter[1] by the Rev. Dr. Inman, whose excellent notes have greatly enhanced the value of this work.

In many of these works we find demonstration, *a priori*, applied to those parts of the subject that admitted it; where this mode of reasoning failed, courses of experiments, judiciously designed and ably conducted, were made the foundation of

[1] This treatise had been previously translated into French by Vial du Clairbois, from which the English translation was principally made.

valuable theories. Many of the properties of ships that were not subjected to strict investigation, were illustrated by general reasoning, and the true direction of future inquiries on the subject pointed out.

A general acquaintance with most of these works is necessary to enable us to form a correct knowledge of the present state of naval architecture. They not only show how much more is known than is generally supposed, but by marking the point to which the different parts of the science are arrived, afford steps to their advancement.

There is, however, another method of extending our knowledge of naval architecture, which may eventually lead to the most important results: the connexion of the experience of naval officers with the scientific knowledge of the naval architect. Every cruize might in a greater or less degree be an experiment; and the enumeration of the good and bad qualities of a ship may be the means of increasing the former, and reducing the latter in future constructions. Correct observations should be made of the qualities of ships under different circumstances, which should be carefully registered. The forms of all ships should be examined in connexion with their qualities, so as to ascertain the particular parts on which they depend. Without such a mode of investigation on scientific principles, there is danger of mistaking casual coincidences for general causes. When by a full examination and comparison of a great number of ships, it is found that a certain form invariably gives the same quality, calculations should be made to determine the law by which a variation in this form, *ceteris paribus*, affects the corresponding quality. In some instances it will be found, that an inverse variation of one dimension produces the same effect as the direct variation of another. This relation should be ascertained between the different dimensions as far as possible, and combinations of these laws made under numerous circumstances. Practical results drawn from such a mode of investigation might be depended on most confidently. This will be a great and decided step in the science, but will require most extensive and correct observations and laborious investigations, with the drawings of all the ships subjected to the experiment.

Many years must necessarily elapse after its commencement, before these laws could be so clearly determined as to be generally applicable to practice; but its accomplishment would be certain, and its utility very extensive.

To render the observations of naval officers more directly applicable to scientific investigation, tables of the different circumstances under which the properties of ships would require to be particularly observed, should be carefully drawn up for their use. The tables at present used are valuable in proportion to their extent, but they require to be rendered more extensive to contribute greatly to the benefit of naval architecture.

It is not by mathematical knowledge alone, nor by experience alone, but by a proper combination of them, that naval architecture may be reasonably expected to be improved. In many parts of the subject, mathematics is fully adequate to determine all that is necessary to be known; and in others, experience subjected to scientific treatment, will be the certain means of improvement.

In England several attempts have been made to improve naval architecture. One of the most considerable, was the establishment of a "Society for the improvement of Naval Architecture" in 1791. It was composed of many nobleman and other gentlemen,[1] highly distinguished for their talents and public spirit. The following year an account was published by the order of the Society, of its institution and proceedings. It contained some papers on naval architecture, several of which were so totally devoid of scientific knowledge, and so contrary to established principles, that it is difficult to account for their insertion. A few of the papers, however, were useful, as containing some good remarks; Chapman's Paper on Tonnage is one of the best of them.

This Society conducted, at a great expense, some experiments on the resistance of fluids in the Greenland Docks, but without deducing any valuable results. These experiments do not appear to have been designed so well as might have been

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[1] Lord Mulgrave, Earl Stanhope, Sir Joseph Banks, Sir Charles Middleton, Dr. Hutton, and Admiral Chapman, were among its supporters.

expected for the development of the laws of the resistance of fluids, and were certainly much inferior to the excellent experiments made by the Royal Academy of Sciences of Paris.

The cause of the comparative inutility of these experiments appears to have been an inadequate knowledge of the extent and difficulties of the subject. A full acquaintance with what had been previously written on the subject would have probably suggested a better course of experiments, more adapted to practical benefit. The energies of the Society appear to have been great, but being improperly directed, they contributed but little to the improvement of this science.

Another attempt to improve the science of naval architecture in this country, was the establishment of a school of naval architecture in His Majesty's dock-yard at Portsmouth in 1810, in conformity with the report of the Commissioners of Naval Revision, under the administration of the Right Honourable Lord Mulgrave, First Lord of the Admiralty.

The term of the studies is seven years, during which time the students receive instruction in mathematics, and the theory and practice of naval architecture. At the expiration of their course of studies, they are appointed to the different dock-yards to improve themselves in the general duties of their profession, till they receive appointments as officers. Previous to their appointment, they are sent to sea in some of His Majesty's ships, to observe their action under different circumstances, as relates both to their form and construction. They are to be promoted, as vacancies occur, to the higher situations in the yards, and to the office of surveyor of His Majesty's navy. Their education prepares them for the investigation of the subject in a manner calculated to improve it; and when some of them who may be best qualified from their scientific attainments to prosecute the subject, shall be taken, at some future period, from the official routine of dock-yard duties, and be enabled to give their undivided attention to the subject, the science of naval architecture will probably be as well known in England as in other countries, and will advance as certainly as other sciences, to which labour and the true philosophical modes of investigation have been applied.

M.

Art. II.—*On the Displacement of a Ship.*

As a floating body always displaces a volume of the fluid equal to its own weight, the weight of a ship may be correctly determined by measuring the content of the part of the body below the water's surface: this is called the displacement of a ship.

In making a design for a ship, its weight, when completely equipped, is the first and most important element to be known. To obtain it, it is necessary to know the dimensions and specific gravity of all the materials to be used in the construction, the number of guns it is to carry, the complement of men, and quantity of provisions and stores it is to have on board. Long calculations are necessary to determine these weights correctly. The labour of this operation is frequently much reduced by ascertaining the displacements of ships of the same class, or as nearly equal as can be obtained, and making the alterations which may be intended in the different elements of the ship to be designed. When the total weight of the ship is determined, it is the first object of the constructor to give a corresponding displacement, with such relative dimensions as he may consider most proper to conduce to the qualities he may wish the ship to possess, to ensure the lower guns being at a sufficient height above the water's surface. A great error in this important point might be attended with the most dangerous consequences; it is, however, less to be dreaded, as it is one of the principles of naval architecture, perfectly within the power of the constructor to determine correctly.

There are several methods used to determine the displacement of a ship, chosen according to the degree of accuracy required in the calculations. Bouguer, in his *Traité du Navire*, gives a simple rule for estimating the displacement, by considering a ship's body a spheroid, to which it assimilates more nearly than to any other regular body. The content of a spheroid being $\frac{11}{21}$ the circumscribing parallelopiped, the displacement will be $\frac{11}{21}$ the solid contained within the three principal dimensions, the length of the ship at the water's surface, the breadth, and the depth. He considers that this

estimate is a nearer approximation to the displacement of full ships than of sharp ones; which latter, he says, will be scarcely $\frac{11}{28}$ the circumscribing solid.[1]

To determine the displacement of a ship to be built from a proposed design, requires much greater correctness than this method. Atwood, in his paper on the stability of ships, in the Philosophical Transactions of the Royal Society of 1798, gives three general rules for approximating to the integral values of differential functions, deduced from Mr. Stirling's Tables, published in his *Methodus Differentialis.*

To use these rules in the determination of the displacement of a ship, it is necessary to obtain equidistant vertical sections of the immersed part of the body, or equidistant horizontal sections parallel to the load-water section. To obtain the areas of these sections by these rules, equidistant ordinates are drawn perpendicular to the middle line; and the solid content of the body is obtained by using these areas as ordinates in these rules.

The three rules are,

$$1. \text{ ——— Area} = P - \frac{S}{2} \times r.$$

$$2. \text{ ——— Area} = S + 4P + 2Q \times \frac{r}{3}$$

$$3. \text{ ——— Area} = S + 2P + 3Q \times \frac{3}{8}r$$

In the first rule, P represents the sum of all the ordinates; S, the sum of the first and last; and r, the common distance between the ordinates.

In the second rule, S is the sum of the first and last ordinate; P, the sum of the 2d, 4th, 6th, &c.; Q, the sum of the 3d, 5th, 7th, &c.; and r, the common distance between the ordinates.

In the third rule, S is the sum of the first and last ordinate; P, the sum of the 4th, 7th, 10th, 13th, &c. (the last excepted); Q, the sum of the 2d, 3d, 5th, 6th, 8th, &c.; and r, the common distance between the ordinates.

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[1] In several examples I have taken, these fractions give considerably less than the true displacement.—ED.

The first of these rules may be used, whatever be the number of ordinates; the second rule requires the number of ordinates to be odd; and the third, the number of ordinates to be a multiple of 3 increased by unity.

Rule 1 supposes a straight line to pass through every two successive ordinates; rule 2 supposes an arc of a common parabola to pass through the extremities of every three successive ordinates; and rule 3, an arc of a cubic parabola to pass through the extremities of every four successive ordinates. By the first rule a considerable error is committed, by neglecting the areas contained between the chords and corresponding arcs of the curve; but in rules 2 and 3, there can be but little deviation from truth, as the curve can differ but little from the arcs of a common or cubic parabola supposed to pass through the extremities of the ordinates.

In measuring a parabola whose equation is $y^8 = a^7x$, y being the ordinate, and x the abscissa, the errors of approximation of the three rules are best shown. Suppose the abscissa = the parameter = 50, and the ordinate 50, the correct area is

	2222,22		
Area by 1st rule,	2205,67	Error,	16,55
—— 2nd ——	2221,76	——	,46
—— 3d ——	2221,22	——	1,00

The displacement being determined in cubic feet by these rules, is brought into tons, by being divided by 35, the number of cubic feet of sea-water in a ton.

The following are the results of calculations made according to these rules:—

The displacement of the Caledonia, of	120	guns,	4803,3 tons.
Bulwark, of	76	——	3144,8 ——
Endymion, of	50	——	1695,0 ——
Icarus, of	10	——	278,8 ——

If the displacement of a ship is determined by equidistant horizontal sections, and the content of the solid contained between every two successive sections obtained, a scale of tonnage may be made, which in some cases may be useful, and the application of which is very simple. Let the line A B represent the mean draught of water of a ship, and let C, D, E, F, and B, be the heights at which the horizontal sections of the displace-

ment are calculated. Draw from these points the lines C *c*, D *d*, E *e*, F *f*, and B *b*, perpendicular to A B, and of such relative lengths, that they shall respectively represent the displacement in tons below the corresponding horizontal sections. Through the points A, *c*, *d*, *e*, *f*, and *b*, let a fair curve be drawn. Let the scales of the figure by which the heights of the horizontal sections are set off, and the lines representing the parts of the displacement below these horizontal sections, be drawn on the lines A B and B *b*. The difference of displacement between any two mean draughts of water may be immediately taken from this curve. Suppose it was required to lighten the ship from B to G, the number of tons of lading that it would be necessary to take out of the ship might be obtained by drawing G *g* parallel to B *b*, and *g* H perpendicular to it; H *b*, according to the scale of B *b*, would determine the number of tons required. This figure should be constructed on a large scale to ensure correctness.

The scale of tonnage might be generally useful for ships, but is particularly applicable to merchant ships.

It is often useful in practice to know the weight of an inch in depth of the displacement at the load-water section; which can differ but little from several successive inches of displacement lower down.

The displacement of one inch in depth at the load-water section of the Caledonia, of 120 guns, is 23,9 tons.

Bulwark, of	76	—	18,3
Endymion, of	50	—	13,4
Icarus, of	10	—	4,2

When the dimensions of a ship are proposed to be increased proportionally, an approximation to the increased displacement may be easily obtained by knowing the displacement of the original. Let x represent the breadth of the original ship, $a\,x$ the length, and $b\,x$ the depth, then $m\,a\,b\,x^3$ will represent the displacement, m representing the fraction of the circumscribing parallelopiped, then $d\,x$ will represent the increase of breadth, and the differential $3\,m\,a\,b\,x^2\,d\,x$ the increase of displacement. Substituting in the proportion $m\,a\,b\,x^3 : 3\,m\,a\,b\,x^2\,d\,x :: x : 3\,d\,x$, the known values, the increase of displacement is immediately found. Suppose the

displacement 3000 tons, the breadth 50 feet, the increase of breadth 6 inches; then 3000 : increase of displ. :: 50 : 1,5 and

$$\text{increase of displ.} = \frac{3000 \times 1,5}{50} = 90 \text{ tons, and the}$$

total displacement of the enlarged ship is 3090 tons.

Supposing a ship is required to be increased, but in such a manner that the dimensions of the new ship may not be proportional to those of the original; an approximate value of the increase of displacement may be obtained by supposing the body of a ship a spheroid, the length at the load-water line being the major axis, and the breadth the minor axis.

As the half breadth and depth, however, are not equal, the sum of these two dimensions must be taken for the minor axis. The proportion of the major axis to the minor, given by Bouguer, as agreeing most nearly with the usual dimensions of ships, is 325 to 100. Taking these numbers for the major and minor axis, the surface of the demi-spheroid is 41641, which is to the rectangle of the two axes 32500, as 128 is to 100.

To determine the increase of displacement by this method, it is only necessary to take the rectangle of the major and minor axis of any ship, and make the following proportion; 100 : 128 :: rectangle of the two axes : surface of the demi-spheroid. This surface being multiplied by the thickness, will give the increase of displacement; and if the increased thickness be not uniform, the surface must be multiplied by the mean thickness.

Rules of approximation on true principles, of easy and quick application, are very valuable in enabling estimates to be made with tolerable accuracy of the effect of proposed alterations, and frequently enable plans to be carried further in the mind than could have been done without these previous steps. Where tedious calculations are necessary to ascertain the effect of any alterations, there is less probability of the subject being prosecuted, when it is casually brought under consideration without an immediate necessity of examining it.

The importance, however, of giving the proper displacement to a ship to be built, requires that the calculations of the design should be conducted with great correctness. In such cases, inaccuracy in the results cannot be compensated by

facility in the mode of obtaining them. The two last rules of Atwood are particularly applicable to this subject on account of their correctness. M.

Art. 3.—*On determining the Centre of Gravity of a Ship.*

Most of the properties of a ship depend in a greater or less degree on the position of the centre of gravity; so that in those cases in which its true position is not known, it is necessary to assume some point which is supposed to be very near it, in relation to which the necessary calculations are made. The point generally assumed is in the load-water section, which can be true at most only in a few ships, as even in those of the same class, different quantities of lading and modes of stowage, must cause it to be differently situated.

The importance of determining this point correctly is generally admitted. Should it be determined for one ship of each class stowed in a manner which is accurately known, it may be easily found for other ships of the same class, differing in the weight or disposition of stores, by making corresponding allowances.

The position of the centre of gravity of a ship is to be considered in relation to the three dimensions, the length, breadth, and depth.

With respect to the first of these dimensions, it is easily ascertained, by finding the position relatively to length of the centre of gravity of the volume of water displaced; a transverse section passing through this point, drawn perpendicularly to the load-water section, passes also, by the principles of hydrostatics, through the centre of gravity of the ship.

With respect to the second of these dimensions, the breadth, it is evidently in the longitudinal plane that divides the ship into two equal and similar parts.

The position of this point, with relation to the depth, is the most difficult to determine. Several methods have been proposed, and some adopted for its determination. A very tedious, but at the same time, a very correct method, is to calculate the momentum of every weight in the ship, from a given

horizontal plane, and to divide the sum of these momenta by the total weight of the ship, which gives the perpendicular distance of the centre of gravity from this plane.

The heights of the centre of gravity of two ships of the line, determined by this method, were as follows:—

Bulwark, of	76 guns,	,7	foot above the load-water section.
Ajax,	74 —	,6	————

A method, which has been recommended, is to make a model in all respects similar to the ship, whose centre of gravity is to be found, and by suspending it from three points, not in the same plane, and continuing the directions of the lines of support on the model, their intersection gives the centre of gravity. This method is, however, wholly unfit for practice, as the time of making such a model as would ensure even tolerable acccuracy, would be very great.

Another method proposed for finding the centre of gravity, is by causing the ship to roll, by the crew going together from side to side, and having persons in boats at the stem and sternpost, to observe the points that do not partake of a circular motion, which are the poles of the axis of rotation, which passes through the centre of gravity of the ship. There is, however, a difficulty in observing these points, on account of the rising and falling of the centre of gravity in consequence of the inclination.

The following method of determining the centre of gravity by experiment, is given by M. Fred. R. Chapman, first published in the Transactions of the Swedish Academy of Sciences, in 1787, and afterwards as a Supplement to a Tract published by him in English, on the determination of the area of the sails of ships of the line. Instead of the stability being calculated by the metacentre, which is adopted by Chapman, the more correct theory of Atwood (see Ph. Trans. of Roy. Society of London, 1796 and 1798,) is substituted in this paper in the calculations connected with the experiment.

Chapman strongly recommends that this experiment should be made in ships of all classes, and under all circumstances,

light and laden, new and old. When ships are in harbour the experiment could be easily made.

The principle on which this method is founded, is this: when a ship is inclined by the removal of any weights on board towards one of the sides, the momentum of these weights is equal to the momentum of the stability, since there is an equilibrium. By determining these momenta, every term in the analytical expressions representing them, is known, except the one depending on the position of the centre of gravity. All the other terms of the equation being known, this is determined.

Let A B C, fig. 2. represent the transverse section of a ship, G the centre of gravity of the ship, D the centre of gravity of the displacement when the ship is upright, E the centre of gravity of displacement when inclined through an angle F G B. The moment of stability is measured by the total weight of the ship multiplied by L G, the distance the vertical pressure of the water acts from the centre of gravity of the ship. Let V represent the total displacement of the ship in cubic feet; then $V \times LG$ is the moment of the stability.

Let each weight be multiplied by the distance it is moved, and let the sum of these momenta be divided by the total sum of the weights moved; and take H I to represent this quantity. Take *any* point N in M F, as by the principles of mechanics, the effect of a weight moved an equal horizontal distance at any height, is the same in causing a floating body to incline; and draw N O perpendicular to it, and equal to H I; draw O P perpendicular and N P parallel to A C. Then the momentum of the weights when the ship is inclined through the angle F G B, putting W equal to the sum of the weights, brought into cubic feet of sea water, is $W \times NP$. Then $V \times LG = W \times NP$.

Now, by Atwood $V \times LG = bA - dsV$, b being the distance between the centres of gravity of the volumes immersed and emerged by inclination, A the volume immersed by inclination, d the distance between the centres of gravity of the ship and the displacement, s the sine of the angle of inclination, V as before the total volume displaced in cubic feet.

Put $c =$ cosine of the angle of inclination; then $W \times NP =$

$$W \times NO.\, c = bA - dsV \therefore d = \frac{bA - W.\, NO.\, c}{sV}$$

All the terms in this expression being known, the value of d is known: that is, the distance between the centre of gravity of the ship, and the centre of gravity of displacement.

The position of the centre of gravity of the displacement being also known, the centre of gravity of the ship is determined.

The method of performing the experiment is as follows:—

"1. Let the ship's company be separated and placed on the decks, quarter-deck, and forecastle, either on the middle, or divided on both sides of the ship, so that it does not incline. Let all the guns be run out above and below; place the quadrant, by which the inclination of the ship is to be measured, and observe the ship's draught of water fore and aft.

"2. Mark the situation of the gun-carriages on the deck.

"3. Haul in the guns either on one or both decks as far as the hatches and other hindrances will allow, some more and others less, till the ship has acquired an inclination of about six or eight degrees. Nail cleats against the trucks of the carriages, that they may stand fast. Let the men take their former stations, and observe exactly how many degrees and minutes the ship inclines.

"4. Number the guns, and measure the distance that each of them has been moved.

"5. Take the weight of each gun, carriage, breeching, and coins, &c. that follow the gun when moved, and reduce this weight to cubic feet of sea water.

"6. Multiply the weight of each gun, &c. by the distance moved, which is the momentum of that gun."

Take the sum of these momenta, which substitute in the expression for $W.\, NO.$ Substitute for the other terms their value determined by calculation.

This will give the value of d, which is the distance of the centre of gravity of the ship from the centre of gravity of displacement. Determine by calculation the situation of the centre of gravity of displacement. This will give the situation of the centre of gravity of the ship.

The facility with which the experiment may be made, and the certainty of the calculations, render it the more desirable that the centres of gravity of ships should be generally determined. M.

Art. IV.—*On the Stowage of Ships.*

By the stowage of a ship is meant the disposition of the ballast and stores. The great effect produced by different modes of stowage, renders this subject one of the most important connected with naval architecture. Most of the properties of a ship depend in some manner on the situation of the centre of gravity, which is determined by the disposition of the moveable weights on board. The great difference found to exist in the qualities of the same ship at different times, arises principally from alterations in the stowage and trim. The astonishing improvements sometimes said to be made in ships by the removal of small weights, might perhaps appear questionable; but as the present state of this branch of the science of naval architecture is not sufficiently known to fix with certainty the best sailing trim, the numerous facts related on the authority of men of experience are to be received with the greater credibility; if not admitting the degree, yet as establishing the principle.

This subject has received the attention of many eminent scientific men as well as experienced naval officers, through whose labours very valuable information has been obtained. In France, the best memoir on the stowage of ships was several times made the subject of a prize by the Royal Academy of Sciences. Daniel Bernoulli received the prize in 1757. M. L. Euler divided the prize of 1759. M. Groignard, *Constructeur des Vaisseaux du Roi, à l'Orient*, composed two memoirs to contend for the prizes in 1759 and 1765. M. l'Abbé Bossut and M. J. A. Euler divided the prize of 1761. M. Bourdé de Villehuet obtained the prize in 1766. Many other excellent memoirs on this subject were presented at the competition for the prizes.[1]

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[1] Some of these memoirs will probably be inserted in our future Numbers.

As the situation of many of the weights in a ship are unavoidably fixed by circumstances, the advantages to be derived from an investigation of the stowage of ships can relate only to the moveable weights: the ballast, and *part* of the stores.

The *quantity* of stores and ballast in a ship is the first consideration in the stowage. The number of months for which vessels should stow provisions, depends on their class and general service. No ship should, however, be incapable of stowing four months' provisions with the ordinary compliment of stores.

The quantity of ballast is dependent on some of the qualities of the ship: chiefly the stability and the lateral resistance opposed to falling to leeward. An increase of ballast must always produce one disadvantage, an increase of the area of direct resistance, which, *cæteris paribus,* would reduce a ship's velocity in the water. By the increase of ballast, however, judiciously stowed, the stability of a ship is frequently increased, so that she will carry so much more sail, that the moving power is increased more than the resistance, and, consequently, the velocity of the ship is increased? The question arising from this consideration is, whether the advantage produced by an increase of ballast could not be obtained by other means, without an equal attendant disadvantage? The stability could be increased in a ship to be built by an increase of breadth preserved above and below the water's surface, as far as the immersion and emersion caused by the inclination, and extending considerably forward and aft. The lateral resistance to prevent the ship's falling to leeward, might be increased by the form below, and forward and abaft. By these means it would not be necessary to increase the quantity of ballast so much as is frequently done. This substitution of form for an increase of ballast cannot, however, probably be carried so far, but that a considerable quantity of ballast will be necessary. To what extent the quantity of ballast in ships might be reduced, might probably be ascertained by experiment.

The properties of a ship which are chiefly affected by the stowage are, the stability, rolling, pitching, holding a steady

course, ardency or tendency to fly up to the wind, going about, action of the rudder, and the strain of the materials. The manner in which the stowage influences these properties will be best seen, by considering them, as far as is possible, independently of other circumstances.

1. The Stability. The disposition of the weights of a ship determines the position of its centre of gravity, which, *cæteris paribus*, increases or diminishes the stability, according to its being lower or higher in the ship. This is as well known in practice as clearly demonstrable by science. The distribution of the ballast as low as possible is therefore always necessary when the stability is required to be increased. The nearer the middle of the ship, in the full parts of the body, the ballast is stowed, the lower it will be, and consequently the greater the stability. This, in almost all cases, is good stowage in relation to the stability of a ship, as the case is rare when the lading of the ship is of such great specific gravity as to render it necessary to raise the weights, by putting articles of less specific gravity under.

2. Rolling. In estimating the influence of the stowage on the rolling of a ship, it must be considered independently of the stability. The permanent inclination caused by the force of the wind depends entirely on the stability; but the vibratory action of rolling depends on other causes, some of which are unconnected with the stability. Two ships of equal stability are frequently known to possess very different qualities in this respect: the one may roll slowly and easily, the other quickly and uneasily.

The rolling of a ship is caused by waves striking a ship's side; it is generally deepest either when a sudden change of wind takes place, and the ship sailing free, is struck on the side by the waves, which continue to run in the direction of the wind before the change; or in a calm, when the swell of the sea gives the body of the ship a constant disposition to incline, without any inclining force of wind to keep the ship steady.

The rolling of a ship is sometimes considered analogous to the vibrations of a pendulum. Supposing some point below the ship to be the point of suspension, the length of the pen-

dulum is measured by each particle into the square of its distance from the centre of suspension, divided by the whole body into the distance of the centre of suspension from the centre of gravity. The length of the pendulum would, therefore, be increased by removing the weights as far as possible from the centre of suspension. The disposition of the moveable weights in a ship according to this consideration, therefore, to increase the length of the isochronal pendulum, would be to place them as far as possible from the vertical and longitudinal plane passing through the centre of gravity. By the increase of the length of the pendulum, the time of the oscillation is increased, so that the ship's rolling would be proportionally slower.

The analogy, however, between the oscillations of a pendulum and the rolling of a ship, cannot be considered strictly correct.

An easier manner of considering the effect of the weights on the rolling of a ship is, simply, by estimating their resistance to rotatory motion by their inertia. As the inertia of any weight is measured by each particle into the square of its distance from the centre of suspension, the placing these weights furthest from the centre of suspension, would most increase their resistance to motion. In a ship, the centre of suspension must be considered to coincide with the centre of gravity; so that the further the weights are removed from the centre of gravity, the greater would be the resistance to quick and uneasy rolling.

The practice of "winging the weights," as it is technically called, suggested by these principles, is found to be fully justified by experience. Care should, however, be taken that the centre of gravity of the weights may not be raised by this disposition, that the stability may not be diminished by it.

Quick and violent rolling is frequently found to be very injurious to the hull and masts of a ship. Many modes of security of the beam-ends and ship's sides have been adopted, which have been of great advantage in sustaining the strain caused by this action. Due consideration to form and *good stowage* are, however, always found greatly to reduce the violence of a ship's rolling.

3. Pitching. When a ship is so far passed over a wave, that the forepart is unsupported by the water, the mean vertical

direction of the water acting abaft the centre of gravity, causes the bows to pitch forward into the hollow of the waves. This motion, as far as it is influenced by the distribution of the weights, is subject to the same laws as the rolling. The further the weights are from a vertical transverse plane passing through the centre of gravity, the greater will be their inertia, and consequently the slower and deeper the pitching. These two motions are, however, to be considered very differently, as to their effect on the ship. The advantage of increasing the time and depth of the rolling has been considered in diminishing the strain of the hull and masts; but the effect of deep pitching must, on the contrary, be considered as disadvantageous, by retarding the velocity of the ship's motion, and rendering it uncomfortable to the men, by the waves breaking over it.

When a ship has passed a wave, the afterpart falls into the hollow of the waves, by the mean vertical direction of the water acting on the fore side of the centre of gravity. This action, which is called scending, is affected by the disposition of the weights similarly to the pitching.

The form of the fore and after parts of a ship determines, in a great degree, these actions of pitching and scending; but as other circumstances frequently require a form not the best calculated to regulate them, it becomes the more necessary that the best disposition of the moveable weights should be made for this purpose. It is therefore necessary to bring as many of the moveable weights as possible near the middle of the ship, to reduce the depth of the pitching and scending.

4. Holding a steady course. When a body moves through any fluid, it is necessary that the lateral resistance abaft the centre of gravity should be greater than before it, to prevent the body having a continual tendency to turn round. This disposition in a ship to turn from the direct course is technically called yawing; it increases the difficulty of steering, and retards the sailing. To prevent this bad quality in a ship, the weights should be so placed that their centre of gravity may be before the middle of the ship's length, by which the moment of the lateral resistance abaft the centre of gravity will be increased, and the moment forward diminished.

5. Ardency. The ardency of a ship, or its tendency to fly up into the wind, depends on the mean direction of the water, the ship sailing by a wind, and the position of the centre of effort of the sails. When a ship is fully stored and properly trimmed, the mean direction of the water passes a little before its centre of gravity. By the loss of the consumable stores, the trim may, by improper stowage, be so much altered, that a ship, which at first possessed a weatherly quality in a proper degree, may either lose it altogether, or have it altered so much as to destroy the excellency of this important quality. The stowage should therefore be so disposed, that the consumable stores should be taken in such proportions from the fore and afterparts of a ship, that the good qualities at first possessed may be retained when lightened. This requires great acquaintance with the qualities of the ship to be stowed, as well as great judgment in the disposition of the ballast and stores.

6. Tacking. The resistance a ship experiences in coming about, depends on the lateral resistance of the parts before and abaft the centre of gravity. This resistance will be proportional to the squares of the lengths of the parts before and abaft the centre of gravity, which will be a minimum when the centre of gravity is in the middle of the length.

7. Action of the rudder. As the rotation of a ship must always be referred to the axes that pass through the centre of gravity, the momentum of the power of the rudder to turn a ship is proportional to the distance of the centre of the mean resistance of the rudder from the centre of gravity. This consideration would lead to the moveable weights being placed so that the centre of gravity of the ship should be before the middle of the length.

8. Strain of the materials. The inequality between the weights in different parts of a ship, and the vertical pressure of the water at the corresponding parts, causes a continual strain on the ship longitudinally, which produces an arching, sometimes technically called hogging. To equalize these two actions, is the mode, immediately suggested by the consideration of the cause of arching, as the best method of preventing it. Circumstances, however, prevent the establishment of this equilibrium; great weights will always necessarily be at the extremities of

the ship, and the buoyancy of the corresponding parts of the body must always be very inadequate to their support, from the leanness of the fore and after parts of the body. As far, however, as circumstances will admit, the principle should be attended to, of placing the weights where the buoyancy of the body is best able to sustain them. This requires the ballast and heaviest stores to be placed in the full parts of the body, towards the midship section; reserving, however, the immediate vicinity of the main-mast free from the heaviest weights.

These are the principal considerations on the stowage of ships; and it happens fortunately, that the modes of stowage required by a due attention to the qualities influenced by it, are generally compatible with one another. The stability requires the greatest weights as low as possible, which is agreeable to concentrating them towards the middle of the ship's length, which is required to produce the best effect on the pitching, tacking, and strain of the materials. Holding a steady course, and the action of the rudder, require the weights to be placed so that the centre of gravity of the ship may be before the middle, but not so much as to be *practically* opposed to the consideration of its being very near to the middle, which reduces the resistance to coming about. The rolling requires the weights to be winged, which may be done by judgment and attention, without raising their centre of gravity, which would diminish the stability.

The result of these observations is, that the moveable weights in a ship should be so disposed, that its centre of gravity may be low and a little before the middle of its length; and that they should be winged as much as possible without raising their centre of gravity.

Chapman says, in his *Treatise on Ship-Building*, that the centre of gravity of a ship should be between the limits of $\frac{1}{50}$ and $\frac{1}{100}$ the length before the middle. This proportion he most probably determined by calculations made on different ships in the Swedish service. The centre of gravity of ships of 74 guns, stowed according to the English method, as to the height of its situation, is generally from about six to nine inches above the load-water line.

These principles govern the stowage of ships; but the man-

ner and degree to which they should be carried into practice, must be ascertained by experiment. A course of experiments on the quantity of ballast, and the best disposition of weights on every class of ships, would be very valuable to the science of naval architecture. By determining the proper trim of the different classes of ships, much valuable information would be obtained for the naval architect in making designs. Many calculations, which are made by assuming the set of the ship in water, but which it is afterwards found necessary to alter, would be made with much greater certainty than at present. It is by a combination of theoretical and experimental knowledge, in this subject as in most others connected with naval architecture, that this science will arrive at excellence.

M.

Art. V.—*On the Resistance of Fluids.*

The resistance of fluids is so intimately connected with many of the branches of naval architecture, that while the laws which govern it remain so partially developed, the advancement of this science will be necessarily very limited.

The properties of a ship may be classed under two heads: those which are brought into action by moving through the fluid, and those which are independent of change of situation. It happens, fortunately, that the properties on which the safety as well as general efficiency of a ship depend, are among the latter, and may be estimated with correctness and certainty; while those which relate to the greater excellency of ships, in those qualities which, although not essential, are of considerable relative importance, are among the former,—the investigation of which is far more difficult. A ship may be constructed with absolute certainty to carry a given lading, and to sail with perfect safety, as relates to upsetting; but to construct a ship with the form most conducive to velocity, is beyond the present knowledge of the resistance of fluids to ensure.

The importance of this subject to naval architecture is the greater, as the action of the wind that moves the ship, as well

as the water which opposes its motion, are dependent on its laws.

Should this subject ever be so fully known as to be applicable with certainty to practice, naval architecture will make a more decided step than it has hitherto made, or than perhaps the most complete acquaintance with any other branch of the science could lead to.

The cause of so little being known on the subject cannot be a neglect of it, as the number as well as the abilities of those who have attended to it have been great; many of the first philosophers and mathematicians having engaged in its investigation. It is probable that its extreme difficulty has been the cause of its slow advancement; and that perhaps as much is known on the subject as, on this consideration, could have been expected.

It is, however, attended with some difficulty to ascertain what is known on the subject. So many theories of the resistance of fluids have been published, and many of them so dogmatically stated, that it would appear, by reading only one of them, that the subject was brought to such a degree of excellency, as to be capable of being applied with facility and certainty to the design of ships; further acquaintance with them, however, shows, by their disagreement, that there is but little that is admitted in common by their authors.

The causes of resistance to a body's motion in a fluid are, the inertia, friction, and tenacity of the fluid. The first of these is properly the object of a theory of resistances; the latter two being probably determinable only by experiments, the results of which may be applicable to practice in their simplest forms. The hydrostatical pressure arising from the elevation of the fluid before, and depression abaft, a body only partly immersed, moving in a fluid, is a circumstance affecting considerably the resistance, and must be properly estimated, in order to render the subject applicable to naval architecture.

The nature of fluids is so little known, and many of the laws which govern them so different from the laws of solids, that the general principles of mechanics are much less certain in their application to this subject than to many others.

Sir Isaac Newton, in the second book of his Principia, defines "a fluid to be any body whose parts yield to any force impressed on it, and, by yielding, are easily moved among themselves." He formed an hypothesis agreeing, as nearly as he could imagine, with the construction of fluids, or at least with what it might be. He considered that the motions lost by the body might be properly taken as measures of the resistance; and as the motions communicated to the particles of the fluid, which were the same as were lost by the body, were, in equal times, as the squares of the velocity, he determined that the resistance the body experienced was also in the same proportion. The results of the experiments he made, which appear to have been very carefully conducted, agreed with this conclusion.

In applying the subject to the resistance of surfaces moving obliquely in a fluid, he estimates the effect by the impulse of the particles of the fluid on the body by the resolution of forces. This relates to the effect of an instantaneous impulse, all the parts of the body being met by the different particles of the fluid.

Now, considering the first particles of the fluid which come in contact with the body to act impulsively, those that follow, it is said, cannot make an impulse unless the former particles were destroyed. Experiments have been made to ascertain the motion of the particles of a fluid in relation to a body moving in it; and according to their results, but few of the particles come in contact with the body, being turned off by those which, meeting the opposing surface at its middle, are deflected, and run round the sides. This would limit all investigations made on the supposition of impulse to instantaneous action; the continued action of the fluid would then be estimated as pressure.

Sir Isaac Newton mentions several of the defects of his theory, and by the little use he made of it, appears to have considered it not greatly to be depended on. He however remarks, at the conclusion of his determination of the curve which, revolving round its axis, will generate a solid, which, moving in the direction of its axis, will be less resisted than any other solid of the same length and breadth, that "he conceives this proposition may be of use in the building of ships." Whether he did or did not limit the application of his investigations of

the resistance of bodies moving obliquely in a fluid to the instantaneous impulse of the particles, it is certain that many of his followers, in the generalization of these principles, have altogether departed from this circumstance.

Among those who have formed theories on these principles, and applied them to the determination of the resistance which ships experience moving in the water, were Euler, Don George Juan, Bouguer, Chapman, and Clairbois. Many of these theories are remarkable for the beauty and power of the analysis, which in some cases appears to have been more attended to than the correctness of the philosophical reasoning.

Daniel Bernoulli published two dissertations on the resistance of fluids, and conducted the second in strict conformity to the established laws of mechanics and hydrostatics. M. d'Alembert has treated the subject with all the attention it required, and has given a theory, considered by many to be conducted in the strictest accordance with the most correct principles.

Numerous experiments have been made to determine data for a correct theory. One of the best courses of experiments ever made was by the Royal Academy of Sciences of Paris. Experiments, on a large scale, were also made by a society in the Greenland Docks near London. Among experiments made by individuals, those made by Romme in France demand particular attention, as the results are not only very curious, but highly important to naval architecture. He affirms that two ships of the same midship section, and same length and depth, whatever their forms may be in other respects, within the limits of the greatest difference of form ever used in naval architecture, will experience the same resistance. Could this be established, the subject would be reduced within much narrower limits than other theories allow. The midship section, with its situation, and the length and depth of a ship, would be the only elements that it would be necessary to determine.

It is not uncommon for the unlearned to prefer the assertion of M. Romme to the difficult theories of other authors, and by reducing the number of the elements he considers influential on the resistance, to arrive at the conclusion, unjustifiable by this or any other theory, that the form of ships' bodies is indifferent to the velocity of their sailing.

To ascertain what credit is to be given to these theories, it will be proper to examine the different courses of experiments in relation to the circumstances under which they were made, to ascertain the allowances necessary for these circumstances, and to compare them with one another; and in the consideration of the different theories, to examine them by the established principles of mechanics and hydrostatics, and by the results of the best experiments. In the application of any theory of resistances to naval architecture, care should be taken, in addition to consistency in other respects, that it should be as much as possible in accordance with the circumstances of the action of ships at sea.

If the theory conducted most strictly according to established principles, and founded on the best experiments, should, from the complex nature of the final analytical results, be incapable of being applied, yet the subject should rather be conducted in this manner, with an endeavour to simplify, by allowing less accuracy, than by obtaining a theory founded on incorrect principles, but easy of application as to analytical form. Facility of application of a theory not established on correct principles only renders the error more dangerous.

In the investigation of the resistance of fluids in this work, the different theories and best courses of experiments will be given in the successive Numbers, and in conclusion, such inductions made, as may appear, from a careful examination of the whole, to be legitimate.

This mode of treating the subject of the resistance of fluids is preferred, as most likely to lead to some practical results, by ascertaining what is fairly and certainly established. By showing the merits and defects of the different theories, it may be the means of determining the propriety of adopting parts of some theories, which, as wholes, may be inadmissible. It will at least have the advantage, by an acquaintance with what has been written on the subject, of preventing the unnecessary labour of retracing the steps of others; and may either lead to the further investigation of a theory, from a point to which it is arrived, or may suggest researches in different directions. It may also prevent, in some cases, the repetition of experiments which have already been satisfactorily made. Should all of

them be found deficient, in analogy, to the action of the water on ships at sea, under any circumstances which might have been made more accordant, this examination would suggest a new course of experiments, which might more immediately tend to the improvement of naval architecture.

The theory of Don George Juan will be given first, having been but little known in this country, and requiring, from the manner of its investigation and difference from most other theories, particular attention. M.

Art. VI.—*An Abridged Translation of the Theory of the Resistance of Fluids, of* Don George Juan.

Don George Juan, the author of this theory of resistance, was a Spanish nobleman of high rank in the naval service of his country, and also a member of most of the principal scientific bodies in Europe; among others, of the Royal Society of London. He possessed considerable mathematical knowledge and experience in his profession, which are shown in his work entitled *Examen Maritimo;* of which Dr. Young has said, "It appears to be the most ingenious and useful work on the theory and practice of seamanship which has yet appeared." This work was published at Madrid, and was translated into French by Leveque, from which the following abridged translation was made.

Don Juan commences his theory by instituting the relation between the velocity with which a fluid would issue through an orifice in a vessel, and the weight which would be supported by a surface occupying the orifice. He supposes the velocity with which the fluid issues from the vessel, to be equal to that acquired by a body falling freely through a height equal to that of the surface of the fluid above the orifice.

If on the surface A B (Fig. 3) we draw two horizontal lines, F G, H T, infinitely near to each other, and on the same surface K L and M N perpendicular to the former two, and also infinitely near to each other, the force which will act on the infi-

nitely small or elementary surface, K L M N, in the direction C D, which is perpendicular to it, may be expressed by $m . a .$ L N . N M; the fluid being supposed at rest, m, the weight of a cubic foot of it, and a, the vertical height, in feet, from the superficies of the fluid to the elementary surface. Now, suppose the fluid to have a free passage through this surface, the velocity u with which the fluid would issue $= 8 \sqrt{a}$; therefore $a = \frac{u^2}{64}$, and by substitution, $\frac{m}{64} . u^2 .$ L N . N M will equal the perpendicular force, acting on the elementary surface. Hence, if we know the velocity with which the fluid issues, we get the perpendicular force, by multiplying the area by the square of the velocity, and by the constant quantity $\frac{m}{64}$.

Suppose the elementary surface to move in the fluid in a direction perpendicular to itself, with a velocity u, we know that the fluid would issue through the same surface, supposing it at rest, with a velocity $= 8 \sqrt{a}$: consequently it will now have a velocity $= 8 \sqrt{} \pm u$; the sign + being used when the surface moves in a direction opposite to the motion of the fluid, and the sign − when the surface and the fluid move in the same direction. Hence the elementary surface will sustain an effort in a direction perpendicular to itself, which is $= \frac{m}{64} . \text{L N} . \text{N M} \; (8 \sqrt{a} \pm u)^2 = m . \text{L N} . \text{N M} \; (\sqrt{a} \pm \frac{1}{8} u)^2$.

Let N O be horizontal, and perpendicular to L N, if η represents the angle M N O, which the horizontal line N O forms with the suface, we have

$$\text{M N} : \text{M O} :: 1 : \sin \eta$$

$$\text{M N} = \frac{\text{M O}}{\sin \eta} = \frac{d\,a}{\sin \eta}$$

and supposing the horizontal line L N $= d\,b$, by substitution,

$$\text{M} . \text{L N} . \text{N M} \; (\sqrt{a} \pm \tfrac{1}{8} u)^2 = \frac{m . d b . d a}{\sin \eta} \; (\sqrt{a} \pm \tfrac{1}{8} u)^2;$$

which is the expression for the resistance acting against the elementary surface L K M N, when moving in a fluid in a direction perpendicular to itself.

If the surface moves in a direction forming with itself any given angle θ, and supposing u to represent the velocity in this direction, u will be to the velocity in the direction perpendicular to the surface, as 1 is to $\sin\theta$; hence the velocity in a perpendicular direction will $= u \sin\theta$. This value being substituted in the foregoing expression for u, which represents the velocity in a perpendicular direction, we have the expression for the resistance on the elementary surface in a perpendicular direction, under these circumstances, $=\frac{m.db.da.}{\sin\eta}(\sqrt{a}\pm\frac{1}{8}u\sin\theta)^2$.

Let DL (Fig. 4) form with the surface any angle ϵ; from D, draw DC perpendicular to the surface, join LC. The angle DLC, or its equal DFG, $=\epsilon$, FG being supposed perpendicular to LD; then if DF represents the perpendicular resistance, DG will represent the resistance in the direction DL, to get the value of which we have

$$DF : DG :: 1 : \sin\epsilon$$

$$:: \frac{m.db.da}{\sin\eta}(\sqrt{a}\pm\tfrac{1}{8}u\sin\theta)^2 : \frac{m.db.da.\sin\epsilon}{\sin\eta}(\sqrt{a}\pm\tfrac{1}{8}u\sin\theta)^2;$$

which is the resistance in the direction DL.

If the resistance in the direction of motion were required, then $\epsilon=\theta$; and consequently the expression would become

$$\frac{m.db.da.\sin\theta}{\sin\eta}(\sqrt{a}\pm\tfrac{1}{8}u\sin\theta)^2$$

Let the vertical plane IED be perpendicular to the elementary surface LKMN, and pass through any point D in DL; and through the base LN of the same surface, the horizontal plane NLA; then, having drawn DAI vertical, draw the perpendiculars AB, DC, AH, and call the angle NLA $=\lambda$; and the angle LDA $=\mu$. Suppose LA $=q$, then we have AE $=q\sin\lambda$, and because in the triangle BAE, $\sin\eta=\sin$ BEA, we have

$$BA = CH = q.\sin\eta.\sin\lambda,$$

and from the right-angled triangle LAD,

$$DA = \frac{LA\cos\mu}{\sin\mu};$$

From the similar triangles, DAH, DIC, EIA, the angle IEA = angle HDA;

therefore the sin HDA $= sin\ \eta$.

$$\text{Hence DH} = \text{DA} \,.\, cos\ \eta = \frac{q \,.\, cos\ \mu \,.\, cos\ \eta}{sin\ \mu},$$

$$\text{and CH} + \text{HD} = \text{CD} = q \,.\, sin\ \eta \,.\, sin\ \lambda + \frac{q \,.\, cos\ \mu \,.\, cos\ \eta}{sin\ \mu}.$$

$$\text{Again, DL} = \frac{q}{sin\ \mu};$$

therefore, in the right-angled triangle CLD, we have

$$\text{LD} : \text{DC} :: r : sin\ \epsilon, \text{ or}$$

$$\frac{q}{sin\ \mu} : q \,.\, sin\ \lambda \,.\, sin\ \eta + \frac{q \,.\, cos\ \mu \,.\, cos\ \eta}{sin\ \mu} :: 1 : sin\ \epsilon$$

$$\therefore \frac{q}{sin\ \mu} \,.\, sin\ \epsilon = q \,.\, sin\ \lambda \,.\, sin\ \eta + \frac{q \,.\, cos\ \mu \,.\, cos\ \eta}{sin\ \mu}$$

$$\text{and } sin\ \epsilon = sin\ \lambda \,.\, sin\ \eta \,.\, sin\ \mu + cos\ \mu \,.\, cos\ \eta.$$

Substituting this value of $sin\ \epsilon$ in the expression for the resistance to the elementary surface in the direction DL, it becomes

$$m \,.\, db \,.\, da \left(sin\ \lambda \,.\, sin\ \mu + \frac{cos\ \mu \,.\, cos\ \eta}{sin\ \eta}\right) . (a^{\frac{1}{2}} \pm \tfrac{1}{8}\, u\ sin\ \theta)^2.$$

From the point N let fall NR perpendicular to LR, and call NR $= dc$; then $db = \dfrac{dc}{sin\ \lambda}$; by substituting this for db, the expression for the resistance becomes

$$m \,.\, dc \,.\, da \left(sin\ \mu + \frac{cos\ \mu \,.\, cos\ \eta}{sin\ \lambda \,.\, sin\ \eta}\right) (a^{\frac{1}{2}} \pm \tfrac{1}{8}\, u\ sin\ \theta)^2.$$

If the horizontal resistance be required, $sin\ \mu = 1$, and $cos\ \mu = 0$; hence the expression becomes,

$$m \,.\, dc \,.\, da\ (a^{\frac{1}{2}} \pm \tfrac{1}{8}\, u\ sin\ \theta)^2.$$

For the vertical resistance, $sin\ \mu = 0$, and $cos\ \mu = 1$; and the expression becomes,

$$m \,.\, dc \,.\, da \frac{cos\ \eta}{sin\ \lambda \,.\, sin\ \eta} (a^{\frac{1}{2}} \pm \tfrac{1}{8}\, u\ sin\ \theta)^2.$$

Suppose the horizontal line NO (Fig. 3) perpendicular to LN, and $= de$, then

$$cos\ \eta : sin\ \eta :: de : da = \frac{de \,.\, sin\ \eta}{cos\ \eta}.$$

By substituting this value in the expression found for the resistance in the direction DL, we have

$$m.db.de\left(\frac{\sin\eta.\sin\lambda.\sin\mu}{\cos\eta}+\cos\mu\right)(a^{\frac{1}{2}}\pm\tfrac{1}{8}u\sin\theta)^2.$$

If the vertical resistance be required, we have $\sin\mu = 0$, and $\cos\mu = 1$, and the expression will become,

$$m.db.de\,(a^{\frac{1}{2}}\pm\tfrac{1}{8}u\sin\theta)^2.$$

Since the angle which the direction of motion forms with the elementary surface is expressed by θ, we have the $\sin\theta = \sin\lambda.\sin\eta.\sin\mu + \cos\mu.\cos\eta$ in the case in which the resistance in that direction is required.

When the direction of motion is horizontal, $\sin\mu = 1$, and $\cos\mu = 0$; hence, in this case, $\sin\theta = \sin\lambda.\sin\eta$; and when the motion is vertical, $\sin\mu = 0$, and $\cos\mu = 1$; consequently $\sin\theta = \cos\eta$.

When the direction of motion is horizontal, the horizontal resistance will be

$$= m.dc.da\,(a^{\frac{1}{2}}\pm\tfrac{1}{8}u.\sin\lambda.\sin\eta)^2;$$

and when the direction of motion is vertical, the vertical resistance will be

$$= m.db.de\,(a^{\frac{1}{2}}\pm\tfrac{1}{8}u\cos\eta)^2.$$

We have supposed a represents the height of the fluid above the elementary surface, when the fluid is at rest. When the surface AB is wholly immersed, we will suppose a only represents the quantity PM (Fig. 3), which is the distance the elementary surface is below a horizontal plane passing through A; and let QP, which is the distance from the surface of the fluid to this plane, be represented by D; consequently the vertical height will no longer be a, but $D + a$, which must be substituted in the expressions already found, instead of a. Hence we have

$$\frac{m.db.da.\sin\epsilon}{\sin\eta}\left((D+a)^{\frac{1}{2}}\pm\tfrac{1}{8}u\sin\theta\right)^2 = m.db.da.$$

$$\left(\sin\lambda\sin\mu+\frac{\cos\mu.\cos\eta}{\sin\eta}\right)\left((D+a)^{\frac{1}{2}}\pm\tfrac{1}{8}u.\sin\theta\right)^2.$$

for the expression for the resistance, estimated in any given direction.

$$m.dc.da\left((D+a)^{\frac{1}{2}}\pm\tfrac{1}{8}u\sin\theta\right)^2$$

for the horizontal resistance:

and $m.db.de\left((D+a)^{\frac{1}{2}}\pm\tfrac{1}{8}u\sin\theta\right)^2$

the vertical.

And if the resistances in the direction of motion are required, as in that case $\epsilon = \theta$, the expressions become,

$$\frac{m \cdot db \cdot da \cdot \sin\theta}{\sin\eta}\left((D + a)^{\frac{1}{2}} \pm \tfrac{1}{8}\, u \cdot \sin\ \theta\right)^2$$

for the resistance estimated in any given direction;

$$m \cdot dc \cdot da\left((D + a)^{\frac{1}{2}} \pm \tfrac{1}{8}\, u \cdot \sin\lambda\ \sin\eta\right)^2$$

for the horizontal; and, lastly,

$$m \cdot db \cdot de\left((D + a)^{\frac{1}{2}} \pm \tfrac{1}{8}\, u \cdot \cos\eta\right)^2$$

for the vertical.

Let CI (Fig. 5) be inclined to the horizon, and represent the superficies of a fluid supposed to be in motion with a constant velocity, by the action of the force of gravity; let B be one of the particles; the force of gravity acts on this particle in the vertical direction BD, which may represent the force of gravity, and be resolved into two other forces, one acting in the direction BA, perpendicular to CI, and the other in the direction AD, parallel to CI. By the action of the first force, the fluid would remain in equilibrium; and by the action of the second, its velocity would be accelerated: but by the supposition, its velocity is constant; therefore $du = 0$. Therefore the sum of the powers acting to augment the velocity $= 0$, and consequently there must be a power acting in an opposite direction, which destroys the power acting in the direction AD.

Suppose the elementary surface KLMN at rest, and the fluid moving against it. It may appear at first that there would be no difference whether the fluid or the surface were in motion; nor would there be, if the gravitation of the particles of the fluid was perpendicular to its superficies; but when the fluid is in motion, this ceases to be the case, as its superficies is no longer level. Suppose, for example, that the fluid moves with a constant velocity u, the superficies CI (Fig. 5) being inclined to the horizon: the vertical gravitation α of the particles in FB may be resolved into two; one, β, acting in the direction BA, perpendicular to the superficies, and the other, γ, parallel to it; then let the angle ADB, which is formed by the superficies and a vertical line, be expressed by ω, we have

$$\beta = \alpha \cdot \sin\omega, \text{ and } \gamma = \alpha \cdot \cos\omega.$$

this last force will be destroyed, and there will remain only the force $\beta = \alpha . sin\, \omega$, perpendicular to the superficies CI; and consequently there will be an equilibrium in the fluid by the action of this force, and its value is that which must be substituted in the preceding formulæ in the place of a.

Now let us suppose the vertical line FB $= a$, we have EB $= a . sin\, \omega$; and substituting this value for a in the expression $a = \frac{{}^{*}A\, u^2}{2\, \alpha}$, we have

$$a . sin\, \omega = \frac{A\, u^2}{2\, \alpha . sin\, \omega}.$$

$$\text{Hence } \frac{\alpha}{A} = \frac{u^2}{2\, a\, sin\, \omega^2}.$$

$$\text{But } \frac{\alpha}{A} = 32.$$

Therefore $32 = \frac{u^2}{2\, a\, sin\, \omega^2}$, and consequently $u = 8\, a^{\frac{1}{2}}\, sin\, \omega$, which is the velocity with which the fluid would issue through an orifice made in B, by the action of a power $\beta = \alpha . sin\, \omega$.

The relative velocity with which the fluid will move in the orifice will then be $= 8\, a^{\frac{1}{2}}\, sin\, \omega \pm u\, sin\, \theta$; and the force acting perpendicularly on the elementary surface, LKMN, will be

$$= m . LN . NM\, (a^{\frac{1}{2}}\, sin\, \omega \pm \tfrac{1}{8}\, u\, sin\, \theta)^2; \text{ or,}$$

when $D + a$ is substituted for a,

$$= m . LN . NM\left((D + a)^{\frac{1}{2}}\, sin\, \omega \pm \tfrac{1}{8}\, u\, sin\, \theta\right)^2.$$

Consequently, if we substitute in the formulæ which have been already found, for the case in which it is the surface which moves, $(D + a)^{\frac{1}{2}}\, sin\, \omega$ in the place of $D + a$, we get the following formulæ:

$$m . d\, b . d\, a\left(sin\, \lambda . sin\, \mu + \frac{cos\, \mu . cos\, \eta}{sin\, \eta}\right) . \left((D + a)^{\frac{1}{2}} sin\, \omega \pm \tfrac{1}{8} u\, sin\, \theta\right)^2$$

for the expression for the resistance in any given direction;

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* The moving force = accelerating force × mass; accelerating force = $\frac{v^2}{2s}$; therefore moving force $= \frac{v^2}{2s} \times$ mass.

$$m\,.\,d\,c\,.\,d\,a\Big((D + a)^{\frac{1}{2}}\,sin\,\omega \pm \tfrac{1}{8}\,u\,sin\,\theta\Big)^2$$

for that of the horizontal; and

$$m\,.\,d\,b\,.\,d\,e\Big((D + a)^{\frac{1}{2}}\,sin\,\omega \pm \tfrac{1}{8}\,u\,sin\,\theta\Big)^2$$

for that of the vertical. And if the expressions be required for the resistance in the direction of motion, we have

$$m\,.\,d\,c\,.\,d\,a\Big((D + a)^{\frac{1}{2}}\,sin\,\omega \pm \tfrac{1}{8}\,u\,sin\,\lambda\,sin\,\eta\Big)^2$$

when that direction is horizontal, and

$$m\,.\,d\,b\,.\,d\,e\Big((D + a)^{\frac{1}{2}}\,sin\,\omega \pm \tfrac{1}{8}\,u\,\;cos\,\eta\Big)^2$$

when it is vertical.

If the fluid moves horizontally, then $sin\,\omega = 1$, and the expressions become the same as for the case in which the fluid is at rest and the surface is in motion; it follows, therefore, that it is only in this case that the generally received principle is correct, that the effect produced is the same, whether the fluid or the surface is in motion.

Suppose AB to be a plane surface in the form of a rectangular parallelogram, placed so that two of its sides shall be horizontal, and let it be in motion in a fluid which is of uniform density, and at rest; the resistance experienced by the elementary surface KLMN, under the supposition that the whole of the surface is not immersed in the fluid, will

$$= \frac{m\,.\,d\,b\,.\,d\,a\,.\,sin\,\epsilon}{sin\,\eta}\,(\sqrt{a} \pm \tfrac{1}{8}\,u\,sin\,\theta)^2;$$

therefore, by supposing b to be the only variable quantity, and integrating, we get the resistance acting on the whole differential rectangle FHIG

$$= \frac{m\,b\,.\,d\,a\,.\,sin\,\epsilon}{sin\,\eta}\,(\sqrt{a} \pm \tfrac{1}{8}\,u\,sin\,\theta)^2.$$

Suppose the same surface, seen in profile, to be represented by AH (Fig. 6), and CD the surface of the fluid in which it moves, we shall have, for some point, as E, in which the surface recedes from the fluid, the force $\dfrac{m\,b\,.\,d\,a\,.\,sin\,\epsilon}{sin\,\eta}(\sqrt{a} - \tfrac{1}{8}\,u\,sin\,\theta)^2 = 0,$

$$\text{or } \sqrt{a} - \tfrac{1}{8}\,u\,sin\,\theta = 0;\ \text{hence}$$

$$a = \tfrac{1}{64}\,u^2\,sin\,\theta^2.$$

Therefore the fluid neither strikes nor compresses the surface in this point, or in any above it; and consequently a hollow or cavity, CEP, will be formed, E being below P by a quantity which is $= \frac{1}{64} u^2 \sin \theta^2$.

In the same manner, by supposing the force

$$\frac{m b \, . \, d a \, . \, \sin \epsilon}{\sin \eta} (\surd a + \tfrac{1}{8} u \sin \theta)^2 = 0, \text{ or}$$

$$\surd a + \tfrac{1}{8} u \sin \theta = 0, \text{ we get}$$

$$a = - \tfrac{1}{64} u^2 \sin \theta^2,$$

giving the height, above P, of a point where the surface ceases to experience any resistance from the fluid. Hence, by the motion of the surface, the level of the fluid is destroyed for the whole length of the surface, and through the whole space CD.

To get the expression for the resistance experienced by a rectangular elementary surface against which the fluid rises, and the loss of pressure sustained by a similar portion of the surface answering to the cavity, we have only to make $\surd a$ negative for the first, and positive for the second. Hence we have, for either force, the expression

$$\frac{m b \, . d a \, . \, \sin \epsilon}{\sin \eta} (a - \tfrac{1}{4} u \sin \theta \surd a + \tfrac{1}{64} u^2 \sin \theta^2),$$

and when it is the fluid which moves, the force is

$$= \frac{m b \, . \, d a \, . \, \sin \epsilon}{\sin \eta} (a \sin \omega^2 - \tfrac{1}{4} a^{\frac{1}{2}} u \sin \omega \sin \theta + \tfrac{1}{64} u^2 \sin \theta^2).$$

Whenever bodies move in fluids, we may observe that the fluid rises against that surface which is opposed to it, and a cavity forms itself behind the surface which recedes from it: we have determined the vertical heights of this rising and falling; but it will be found, in fact, that the height of the rising is not the same through the whole of its length; neither is the surface corresponding with the cavity totally exempt from pressure; for the fluid falls from the centre of the rising towards its extremities, in a direction which is perpendicular to the motion of the surface, and also it runs round the sides of the surface into the cavity; thus diminishing the resistance in the one case, and augmenting the pressure in the other.

If we suppose CB or DB (Fig. 6) to be an abscissa, and BI an ordinate, and that the surface AH passes in a given time from CB into AH, or from AH into DB, all the particles of the

fluid, as I, in the surface of the curve, will have described in the same time their corresponding ordinates, which will consequently be proportioned to the velocities of the particles, or will be $= 8 \sin \omega \sqrt{CB}$, or $8 \sin \omega \sqrt{DB}$. Hence, then, making CB or DB $= x$, and BI $= y$, we have

$$8 \sin \omega \sqrt{x} = y, \text{ or } 64 \sin \omega^2 x = y^2,$$

the equation to a parabola, of which the parameter $= 64 \sin \omega^2$, and of which the axes are CB, DB, being distant from P a quantity CP $= 8 \sin \omega \sqrt{PE}$,

$$* = 8 \sin \omega \left(\frac{u^2 \sin \theta^2}{64 \sin \omega^2}\right)^{\frac{1}{2}} = u \cdot \sin \theta.$$

The expression for the resistance in any given direction,

$$\frac{m \cdot d\,b \cdot d\,a \cdot \sin \epsilon}{\sin \eta}\left((D + a)^{\frac{1}{2}} \sin \omega \pm \tfrac{1}{8}\, u \sin \theta\right)^2,$$

may be reduced to the expression for the horizontal resistance,

$$m \cdot d\,c \cdot d\,a \left((D + a)^{\frac{1}{2}} \sin \omega \pm \tfrac{1}{8}\, u \sin \theta\right)^2,$$

by substituting $d\,c$ for $\dfrac{d\,b \cdot \sin \epsilon}{\sin \eta}$.

Hence, to reduce the expression for the resistance in any given direction, from the expression for the horizontal resistance, we must substitute

$$\frac{d\,b \cdot \sin \epsilon}{\sin \eta}, \text{ for } d\,c, \text{ or } \frac{b \cdot \sin \epsilon}{\sin \eta}, \text{ for } c,$$

$\dfrac{\sin \epsilon}{\sin \eta}$ being constant, while referring only to plane surfaces.

To find the horizontal force acting on a plane surface, in the form of a rectangular parallelogram, moving in a fluid which is at rest, having two of its sides parallel to the horizon, and supposing a part of it to be out of the fluid which is equal to, or greater, in height, than $\frac{1}{64} u^2 \sin \theta^2$

The horizontal force acting on the elementary surface KLMN $= m \cdot d\,c \cdot d\,a\,(a^{\frac{1}{2}} \pm \frac{1}{8}\, u \sin \theta)^2$; then, supposing c the only variable, and integrating, we get the expression for the

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* Suppose $a^{\frac{1}{2}} \sin \omega + \frac{1}{8}\, u \sin \theta = 0$

$$a^2 = \frac{u^2 \sin \theta^2}{64 \sin \omega^2} = PE.$$

force acting on the rectangle FHIG$=m\,.\,c\,.\,d\,a\,(a^{\frac{1}{2}}\pm\frac{1}{8}\,u\,sin\,\theta)^2$; and the force acting on the whole surface will be

$$m\,c\,(\tfrac{1}{2}\,a^2\pm\tfrac{1}{6}\,a^{\frac{3}{2}}\,u\,sin\,\theta+\tfrac{1}{64}\,a\,u^2\,sin\,\theta^2)+\mathrm{H}.$$

To determine the value of H, we must consider, that if there were no alteration in the level of the surface of the fluid, the integral would vanish when $a=0$, and therefore H would $=0$.

This would be the case in the surface opposed to the fluid, if it were not partly out of it; but being so, it becomes necessary to add some quantity, to get the true value of the force acting against the surface opposed to the fluid; the other surface, or that which recedes from the fluid, does not experience any pressure in the part corresponding to the cavity; H then will express the quantity which must be added in the one case, and subtracted in the other, to get the correct forces.

Now, if we make $a^{\frac{1}{2}}$ negative in the above integral, it will become $m\,c\,(\frac{1}{2}\,a^2-\frac{1}{6}\,a^{\frac{3}{2}}\,u\,sin\,\theta+\frac{1}{64}\,a\,u^2\,sin\,\theta^2)$; and substituting for a the value which we have found $=\frac{1}{64}\,u^2\,sin\,\theta^2$, we have the resistance arising from the alteration in the level, or

$$\mathrm{H}=m\,c\left(\frac{u^4\,sin\,\theta^4}{2\,.\,64^2}-\frac{u^4\,sin\,\theta^4}{6\,.\,8\,.\,64}+\frac{u^4\,sin\,\theta^4}{64^2}\right)=$$

$\dfrac{m\,c\,.\,u^4\,.\,sin\,\theta^4}{6\,.\,64^2}$, and the whole force acting against the surface is $=$

$$m\,c\,\left(\tfrac{1}{2}\,a^2\pm\tfrac{1}{6}\,a^{\frac{3}{2}}\,u\,sin\,\theta+\tfrac{1}{64}\,a\,u^2\,sin\,\theta^2\pm\frac{u^4\,sin\,\theta^4}{6\,.\,64^2}\right)$$

the sign + being for the surface opposed to the fluid, and the sign — for the surface receding from it.

If the height of the rise or fall of the fluid, or $\frac{1}{64}\,u^2\,sin\,\theta^2$, be very small in comparison to a, the total height of the immersed surface, then the alteration need not be taken into account in the expression for the force, or we may neglect all the terms, as $\dfrac{u^4\,sin\,\theta^4}{6\,.\,64^2}$, in which a is not found.

If the upper part of the surface coincides with the surface of the fluid, the whole force acting upon the surface opposed to the fluid will become

$$=m\,c\,(\tfrac{1}{2}\,a^2+\tfrac{1}{6}\,a^{\frac{3}{2}}\,u\,sin\,\theta+\tfrac{1}{64}\,a\,u^2\,sin\,\theta^2);$$

but that acting upon the receding surface will be

$$= m\,c\left(\tfrac{1}{2}\,a^2 - \tfrac{1}{6}\,a^{\frac{3}{2}}\,u \sin\theta + \tfrac{1}{64}\,a\,u^2 \sin\theta^2 - \frac{u^4 \sin\theta^4}{6\,.\,64^2}\right).$$

If the surface is immersed entirely in the fluid, so that D has a value, the horizontal force acting on the elementary part will be

$$= m\,c\,.\,d\,a\left((D + a)^{\frac{1}{2}} \pm \tfrac{1}{8}\,u \sin\theta\right)^2;$$

and its integral,

$$m\,c\,.\left(D\,a + \tfrac{1}{2}\,a^2 \pm \tfrac{1}{6}\,(D + a)^{\frac{3}{2}}\,u \sin\theta + \tfrac{1}{64}\,a\,u^2 \sin\theta^2\right) + H$$

will be the expression for the whole surface.

To find the value of H, we know the integral will $= 0$, when $a = 0$, the fluid not exerting any action above the upper part of the surface; hence, supposing $a = 0$,

$$H = m\,c\,(\mp\,\tfrac{1}{6}\,D^{\frac{3}{2}}\,u \sin\theta,)$$

and the expression for the horizontal resistance experienced by the surface will =

$$m\,c\left(D\,a + \tfrac{1}{2}\,a^2 \pm \tfrac{1}{6}\left((D + a)^{\frac{3}{2}} - D^{\frac{3}{2}}\right)u \sin\theta + \tfrac{1}{64}\,a\,u^2 \sin\theta^2\right).$$

Now, from this expression for the horizontal force, we may get that for the force acting in any given direction, by substituting $\dfrac{b \sin\epsilon}{\sin\eta}$ for c.

To find the horizontal resistance acting against any surface moving in a fluid:—After dividing the surface, by means of horizontal and vertical planes, into a number of quadrilateral plane surfaces, find the positive or negative forces which act on each of them; and then, by taking the sum, get the value of the whole force.

Suppose a to be the vertical height of one of these small quadrilaterals, and D the distance of its upper extremity from the surface of the fluid, then

$$m\,c\,.\,d\,a\left((D + a)^{\frac{1}{2}} \pm \tfrac{1}{8}\,u \sin\theta^2\right)^2$$

will be the expression of the horizontal force acting on a differential portion of the small quadrilateral: and the integral,

$$mc\left(Da+\tfrac{1}{2}a^2 \pm \tfrac{1}{6}u\left((D+a)^{\frac{3}{2}}-D^{\frac{3}{2}}\right)\sin\theta+\tfrac{1}{64}au^2\sin\theta^2\right)$$

will be the force acting on the whole quadrilateral.

Now we may make D represent the vertical height from the superficies of the fluid to the centre of the small quadrilateral, by substituting $D-\frac{1}{2}a$ for D, then the expression for the whole force acting on the quadrilateral will become

$$mc\left(Da \pm \tfrac{1}{6}u\left((D+\tfrac{1}{2}a)^{\frac{3}{2}}-(D-\tfrac{1}{2}a)^{\frac{3}{2}}\right)\sin\theta+\tfrac{1}{64}au^2\sin\theta^2\right)$$

and that acting on the whole surface, which is the sum of all the above forces which we shall get, will be

$$m\int c\left(Da \pm \tfrac{1}{6}u\left((D+\tfrac{1}{2}a)^{\frac{3}{2}}-(D-\tfrac{1}{2}a)^{\frac{3}{2}}\right)\sin\theta+\tfrac{1}{64}au^2\sin\theta^2\right).$$

It is evident that in either the rise, or the fall of the fluid, the force will

$$=m\int c\left(Da - \tfrac{1}{6}u\left((D+\tfrac{1}{2}a)^{\frac{3}{2}}-(D-\tfrac{1}{2}a)^{\frac{3}{2}}\right)\sin\theta+\tfrac{1}{64}au^2\sin\theta^2\right)$$

By reducing the quantity $(D+\frac{1}{2}a)^{\frac{3}{2}}-(D-\frac{1}{2}a)^{\frac{3}{2}}$ to a series, we have $\frac{3}{2}D^{\frac{1}{2}}a\left(1-\frac{a^2}{96\,D^2}-\frac{a^4}{2048\,D^4}-\&c.\right)$; and by substitution, we have the horizontal force on one of the quadrilaterals =

$$mc\left(Da \pm \tfrac{1}{4}D^{\frac{1}{2}}au\sin\theta\left(1-\frac{a^2}{96\,D^2}-\frac{a^4}{2048\,D^4}-\&c.\right)+\tfrac{1}{64}\cdot au^2\sin\theta^2\right).$$

If D were very great in comparison to a, we might neglect all the terms of the series, except the first, and this might also be done in respect to all the small quadrilaterals contiguous to the surface of the fluid; for since D represents the vertical height of the superficies of the fluid above the centre of the small quadrilateral, we have in this case $D=\frac{1}{2}a$; and by making this substitution in the series, it becomes $1-\frac{1}{24}-\frac{1}{128}-$, &c. Hence, even in this extreme case, all the terms of the series are of small value in comparison with the first, and a being always very small when compared with D, the series may generally be reduced to its first term.

To find the vertical force which acts on any surface which is in motion in a fluid at rest, the whole surface must be divided into a number of quadrilateral planes; and then the positive or negative vertical force acting on each of these must be found;

and then their sum taken, which will give the whole vertical force. This process has been already explained in finding the horizontal force, and the expression for that force may be reduced to the expression for a force acting in any given direction, by substituting $\frac{b \,.\, sin\, \epsilon}{sin\, \eta}$ for c. But since, in the present case, it is the vertical resistance which is required, the $sin\, \epsilon = cos\, \eta$, and it is consequently $\frac{b\, cos\, \eta}{sin\, \eta}$, which must be substituted in the formula

$$m\int c\left(\mathrm{D}\, a \pm \tfrac{1}{6}\, u\left((\mathrm{D} + \tfrac{1}{2}\, a)^{\frac{3}{2}} - (\mathrm{D} - \tfrac{1}{2}\, a)^{\frac{3}{2}}\right) sin\, \theta + \tfrac{1}{64}\, a\, u^2 sin\, \theta^2\right)$$

to get the expression for the vertical force acting on any given surface.

Now to find the horizontal resistance experienced by a body moving in a fluid: we will take the case of a rectangular parallelopiped floating on a fluid, having two of its sides parallel to the horizon, and supposing the direction of its motion to be parallel to two other of its sides; also that the body shall be partly out of the fluid, and that the part out of the fluid shall be either equal to, or greater, in height, than $\frac{u^2\, sin\, \theta^2}{64}$.

The force acting against the surface opposed to the fluid is =

$$m\, c\left(\tfrac{1}{2}\, a^2 + \tfrac{1}{6}\, a^{\frac{3}{2}}\, u\, sin\, \theta + \tfrac{1}{64}\, a\, u^2\, sin\, \theta^2 + \frac{u^4\, sin\, \theta^4}{6\,.\,64^2}\right);$$

and the force acting on the receding surface =

$$m\, c\left(\tfrac{1}{2}\, a^2 - \tfrac{1}{6}\, a^{\frac{3}{2}}\, u\, sin\, \theta + \tfrac{1}{64}\, a\, u^2\, sin\, \theta^2 - \frac{u^4\, sin\, \theta^4}{6\,.\,64^2}\right).$$

The force acting on the two sides parallel to the direction of motion will = 0; for in their case $c = 0$, and for the lower surface, $d\, a = 0$; therefore the resistance on that will also = 0.

Now the force acting on the receding surface, being in a contrary direction to the force acting against the surface opposed to the fluid, must be taken negatively, and therefore subtracted from the other, which will give the expression for the resistance =

$$m\, c\left(\tfrac{1}{3}\, a^{\frac{3}{2}}\, u\,.\, sin\, \theta + \frac{u^4\, sin\, \theta^4}{3\,.\,64^2}\right) = \tfrac{1}{3}\, m\, c\, u\, sin\, \theta\left(a^{\frac{3}{2}} + \frac{u^3\, sin\, \theta^3}{64^2}\right).$$

If the depth a, to which the lower surface of the parallelopiped is plunged in the fluid, be very great when compared with

the quantity $\frac{1}{64} u^2 \sin \theta$, we may neglect all those terms in the expression for the resistance which do not involve a; and consequently the resistance will become $= \frac{1}{3} m c u \sin \theta\, a^{\frac{3}{2}}$.

If the parallelopiped is entirely immersed in the fluid, and D is equal to, or greater than, $\frac{1}{64} u^2 \sin \theta^2$, then the force acting on the surface opposed to the fluid will be =

$$m c \left(\mathrm{D}\, a + \tfrac{1}{2} a^2 + \tfrac{1}{6} u\left((\mathrm{D} + a)^{\frac{3}{2}} - \mathrm{D}^{\frac{3}{2}}\right) \sin \theta + \tfrac{1}{64} a u^2 \sin \theta^2\right)$$

and that acting on the receding surface will be

$$m c \left(\mathrm{D}\, a + \tfrac{1}{2} a^2 - \tfrac{1}{6} u\left((\mathrm{D} + a)^{\frac{3}{2}} - \mathrm{D}^{\frac{3}{2}}\right) \sin \theta + \tfrac{1}{64} a u^2 \sin \theta^2\right)$$

Subtracting this last expression from the former one, we get the resistance $= \frac{1}{3} m . c . u . \sin \theta \left((\mathrm{D} + a)^{\frac{3}{2}} - \mathrm{D}^{\frac{3}{2}}\right)$.

By reducing $(\mathrm{D} + a)^{\frac{3}{2}}$ to a series, the expression becomes

$$= \tfrac{1}{3} m c \mathrm{D}^{\frac{1}{2}} a u \sin \theta \left(1 + \frac{a}{4 \mathrm{D}} - \frac{a^2}{24 \mathrm{D}^2} +, \&c.\right).$$

If D be very great when compared with a, all the terms, excepting the first, may be neglected; and the resistance will become $= \frac{1}{3} m c \mathrm{D}^{\frac{1}{2}} a u \sin \theta$.

If the parallelopiped has its upper surface level with the superficies of the water, then there will be no resistance arising from the rise of the water against the surface opposed; but there will be a diminution of pressure against the receding surface: consequently the expression for the resistance to the surface opposed to the fluid will be

$$m c \left(\tfrac{1}{2} a^2 + \tfrac{1}{6} a^{\frac{3}{2}} u \sin \theta + \tfrac{1}{64} a u^2 \sin \theta^2\right),$$

and the expression for the other surface will be

$$m c \left(\tfrac{1}{2} a^2 - \tfrac{1}{6} a^{\frac{3}{2}} u \sin \theta + \tfrac{1}{64} a u^2 \sin \theta^2 - \frac{u^4 \sin \theta^4}{6 . 64^2}\right),$$

which, when subtracted from the former one, gives the expression for the resistance =

$$\tfrac{1}{3} m c u \sin \theta \left(a^{\frac{3}{2}} + \frac{u^3 \sin \theta^3}{2 . 64^2}\right).$$

Since the length of the parallelopiped, in the direction of its motion, is not involved in any of the expressions for the horizontal resistances which it experiences under the different cir-

cumstances in which they have been investigated, it follows that the resistance will be the same, whatever may be its length.

Don Juan then proceeds to consider what effect the alterations of the level of the superficies of the fluid produced by certain surfaces, will have on the resistances experienced by other surfaces. But as this investigation is not necessary for the elucidation of his theory, and as he concludes the results deduced are not applicable to the purposes of naval architecture, it is unnecessary to enter on the subject. C.

Art. VII.—*Remarks on the Raking of Ships' Masts, by* Mr. W. Henwood, *Naval Architect.*

One of the many instances of the want of fixed principles in naval architecture, is that of determining the positions of masts. The practice and experience of a long series of years have established rules, according to which the masts of ships are generally placed; yet the frequent recurrence of ships requiring the position of their masts to be altered, shows that these rules are not of general and certain application. The different forms of ships, and particularly the relative degrees of fineness of the fore and after bodies, are necessary elements to be included in all rules for determining the position of the masts. To obtain such rules as will always determine their position in relation to the properties of ships, will require a combination of experimental and theoretical knowledge, greater, perhaps, than the present state of the knowledge of naval architecture admits.

Among other difficulties of this subject, the rake given to masts of ships is frequently a question concerning which there is considerable difference of opinion, and the propriety of which is often doubted.

In some instances the sailing of ships whose masts are too far forward is improved by the rake of the masts being increased, which carries the surface of sail further aft; but the desired effect would be better gained, as far as regards this consideration, by carrying the masts wholly further aft. The advantage of raking masts must be considered on other principles.

The French, and the Americans especially, have carried the practice of raking masts to a greater extent than the English; and as some of their vessels, in which the masts have been much raked, have been remarkable for their superior sailing, it naturally becomes a question, whether or not the peculiar manner of placing the masts has, in any degree, contributed to produce this excellency?

In examining this question, it will be necessary to consider in what way the surface of the sails is subjected to the action of the wind, both when the masts are upright and when they are inclined.

Suppose the masts of a ship to be placed perpendicularly to the surface of the water; then, if the yards were braced up, the tacks and sheets close-hauled, and the ship in an upright position, the planes of the sails would be vertical; and if the ship, when sailing by the wind, could be prevented from heeling, the planes of the sails would receive the impulse of the wind in the most advantageous manner possible. But as it is impossible to prevent the heeling, the planes of the sails cannot remain vertical when they receive the action of the wind.

If the masts, instead of being upright, were to be inclined towards the stern, the planes of the sails, when they are close-hauled, and the ship is upright, would be inclined to the horizon; and as the ship is heeled by the force of the wind, this inclination of the planes of the sails is gradually diminished, and it may be reduced to nothing, if the inclination of the masts was to be in a given proportion to the angle of heeling. Thus, if the angle to which the ship may generally be permitted to heel is 10°, if the rake of the masts was such that the inclination of the common section of the sails, when close-hauled, with an athwartship vertical plane, was also 10° when the ship became inclined, the sails would become vertical.

Again, when the masts are placed perpendicularly, the area of sail presented to the wind, when the ship is upright, is greater than when the ship is heeled, in the proportion of radius to the cosine of the angle of heeling; but when the masts are raked, the area increases as the ship is heeled, in the proportion of the cosine of the inclination of the ship to the radius.

It appears, therefore, in order to make a ship sail by the

wind with the greatest degree of velocity, the masts should be placed at a certain angle of inclination towards the stern, and not in a vertical position.

In the above reasoning, the sails of a ship have been considered as plane surfaces; it has also been supposed that the wind acts uniformly all over their surfaces. Both of these hypotheses, however, are inaccurate. It must be considered in what manner this circumstance affects the above conclusion.

When a ship is sailing by the wind, the curvature of the sails is very small on the weather side, although it is very considerable near the leech on the lee-side; also, as the particles of air impinge very obliquely on the surface of the sails, and as each particle, in gliding off after impact, takes off a part of the action of some of the more leewardly particles, the effective action of the wind on the sails must be gradually diminished from the weather-side to the lee-side. The rush of air across the ship may also probably produce a diminution of pressure on the fore-side of the sail near the weather-leech, which is not the case in the vicinity of the lee-leech.

From these considerations, it appears that the pressure of the wind, on a sail that is trimmed sharp, is greater on the weather-side, where the surface is nearly coincident with a plane, than it is on the lee-side, where the surface is much curved, and that the diminution of pressure is gradual, from the one side to the other. This is confirmed by the well-known fact, that when a ship is on a wind, the tension on the weather braces is always greater than that on the lee ones; and also, by the general proposition, that a plane surface, which is acted on by a fluid in an oblique direction, always endeavours to assume a position perpendicular to the line of action.

It appears, then, from the above observations, that the inaccuracy of the hypotheses admitted respecting the surface of the sails, and the manner in which they are acted on, cannot materially affect the justness of the former conclusion; for the part of the sail which receives the greatest part of the force of the wind does not differ greatly from the circumstance supposed in the reasoning, and the part least agreeable to the supposition does not require any reasoning which opposes the principle of the argument.

The writer is aware that there are other considerations relat-

ing to the raking of ships' masts, and that objections are sometimes made to the practice, particularly by the increased strain brought on the materials by it; he is, however, the more desirous to offer arguments in its favour, as it has received the sanction of experience, and considers that the above reasoning, as far as it goes, is correct in its conclusion; that masts, to produce the best effect on ships' sailing, should be placed at a certain inclination towards the stern.

ART. VIII.—*On the Timber used for the Masts of Ships; communicated by* JOHN FINCHAM, ESQ., *Superintendent of the School of Naval Architecture in His Majesty's Dockyard at Portsmouth.*

To obtain the best timber for the masts of ships is of very great importance, not only on account of their great expense, but because the safety of the ship frequently depends on their quality.

If timber used for most purposes have strength and durability, it possesses the necessary qualities; while the timber for masting must not only have the necessary strength and durability, but also, as far as possible, lightness, flexibility, and elasticity. By its specific gravity, the stability of the ship is not only affected, but, in proportion to its weight, must the support necessary to sustain it be increased. If the mast possesses so great a degree of rigidity as not to yield to the sudden impulses to which it is subject, it soon becomes fractured; and if its resilience, when bent, is not sufficient to cause it to recover its true position, it becomes upset, and is rendered weaker at every impulse.

The timber commonly used for masts is fir and pine, which are distinguished according to the character of their leaves and cones.—Duhamel says, "that the leaves of the pines are slender and filaceous, more or less long, according to the species; two, three, or more of these thin leaves proceeding from the same bud. It is this characteristic which distinguishes them from the fir, whose leaves are straight and separate, and all

proceeding from one slight stem, similar to the teeth of a comb."

The timber used for masts is distinguished, by mast-makers, by the name of the place from which it is imported: as, the Norway and Riga firs, Canada red and white pines, &c.

The timber that possesses, in the greatest degree, the qualities the best suited for masting, is *pinus silvestris Genevensis vulgaris,* from the north of Europe, from the vast forests of Russia, Norway, and Poland; that which is most esteemed is obtained from the forests of the Ukraine and Livonia; it is brought down the Dwina, and is commonly called Riga, on account of its being shipped from that port. In the same way the Adriatic fir derives its name from being shipped in the Adriatic.

The great expense of Riga timber, and the difficulty there frequently is of obtaining it in time of war, have been an inducement to Great Britain, as well as to other nations, to endeavour to have resources for masting their navy within their own states and colonies.

The different firs and pines, besides those of the North, used for masting the royal navy of Great Britain, and likewise to a great extent her commercial navy, are principally those from Canada, with some from Nova Scotia, and a few from Scotland. The timber from Canada consists chiefly of the white or yellow pine, *pinus strobus,* commonly called the Weymouth, or white masting pine; and the white, red, and black spruce, *pinus Canadensis.* The Scotch fir, *pinus silvestris,* is common to the Highlands of Scotland, as well as to Norway, Denmark, and Sweden.

The standing masts are generally made of the yellow, and topmasts of the red, pine; the white, red, and black spruce are but little used, except for small spars. Although the red and yellow pines do not possess, in an eminent degree, those good qualities which are found in those of the North, yet they have them to such an extent, especially the red pine, as qualifies them for the purposes for which they are employed. The Adriatic fir is frequently used for the masts of cutters and other small vessels, but does not possess particularly good qualities.

The woods that have been partially used for masts, are the Poon from the East Indies, and the Cowrie. The Poon has

been used for masting ships built in India; the Cowrie is brought from New Zealand, and has been used for small standing masts, and for topmasts as high as those of frigates, and even for a first-rate. It possesses many of the most esteemed qualities for masting, and will probably be found to be a wood very eligible for this purpose. The cowrie resembles the pine, in being coniferous, and containing a considerable quantity of resin, which exudes from it spontaneously.

The French, according to Forfait, M. le Ray, De Castries, and others, have received considerable supplies from Corsica, from the Pyrenees, and some from the Alps. To obtain supplies from the Pyrenees, they took immense pains to cut roads from the forests to the plains. They appear, likewise, to have received supplies from Catalonia, Savoy, from the Departments of Mont Blanc, Puy de Dome, and Cantal. These firs, however, contain but little resinous substance; the heart is porous, the grain coarse; their flexibility is very trifling; and, from a quick evaporation of their substances, they soon become dry, so that they break under very slight strains.

The pines from the Pyrenees are also inferior to those of the North, having but a small quantity of resinous substance in them, which soon evaporates; and, from the difference of the soil, they are very variable in quality; many, however, are of a fine grain, and of considerable strength and elasticity, until they become dry. Those from Corsica, *pinus halepensis*, of which species many grow on the Mediterranean side of France, Spain, Italy, Asia Minor, and Barbary, and likewise some on the south-east of France, have more resin in them, and are harder and considerably better than those from the Pyrenees.

The Turks obtain excellent firs from the shores of the Black Sea, from the Bosphorus to Sinope; they are commonly of the species denominated *pinus pinea*, and *pinus laricis*: they are of better quality than is common to these species, and are little inferior to those of the North. These trees are plentiful near the Olympus, and in the interior of Asia Minor; the stem is straight, and grows to a considerable height and size. The Turks use them not only in masting, but likewise in the construction of the hull.

In selecting firs for masting, the climate, aspect, and soil in which they grow, are to be considered. The state of the tree, when standing, may be known, in a great measure, from the luxuriance of its upper branches: if they are dead, or do not appear flourishing, the tree may likewise be considered on the decay.

To judge of the qualities of trees while standing, belongs more immediately to those employed in the forests; while the mast-maker is left only to make his choice of the trees when felled, and whose attention is only drawn to their appearance as timber.

To become familiar with the different kinds and qualities of fir-timber, requires considerable practice and close observation, with likewise a proper acquaintance with some of the general appearances that distinguish these qualities. The firs most desirable are those with a fine and close grain, where the ligneous layers are closely blended together, and with the annual and concentric circles fine and firmly connected, and decreasing gradually from the heart to the sap. The nearer the concentric layers are to circles or ellipses, the less likely is the timber to be defective, as sudden swells are very frequently caused by rindgalls. They are also generally strongly charged with resin, which is not only beneficial in giving strength and elasticity, but preserves the timber from insects, and prevents fermentation and decay. The colour should be of a clear or bright yellow, with a reddish cast alternately. The smell in the Riga, and other firs of this quality, should be strongly resinous, especially when they are exposed to the sun, or any other heat, or when their shavings are rubbed between the fingers. On the contrary, when the layers are separate, porous, or open, with tints of a pale red near the heart, and white spots intermixed, or of a dark red with the resinous particles of a blackish colour, the timber is in a state of decay. Likewise, when the firs are cut transversely, and are of a colour not uniform, but interspersed with veins, and the smell is either entirely gone or become fetid, they may be considered past their prime, and approaching to a state of decay. In yellow and red pines that have not the strong resinous smell, the degree of unsoundness is denoted by the offensiveness of the smell; and they will,

in common with other firs, have alternate layers of a foxy brown or red colour, and will break out before the sharpest plane in being wrought.

The experienced mast-maker forms his opinion of the quality of a stick, not only from the colour, smell, and appearance of the grain, but by its working; for as a stick is more or less frough or fragile, the greater or less difficulty he has in separating its parts, as he chops them off. If the timber is good, its parts, on being separated, appear stringy, and oppose a strong adhesion; and the shavings from the plane will bear to be twisted two or three times round the fingers: whereas, if the stick is of a bad quality, or in a state of decay, and has lost its resinous substances, the chips and shavings come off short and brittle, and with much greater ease.

The following experiments the writer made, to ascertain the principal relative qualities of timber used for the masts of ships. The experiments were made on a larger scale than usual; so that small defects, to which they are always liable, could not greatly affect the results. They were also conducted with great attention and care.

TABLE I.

Experiments on Pieces three inches square and two feet long beyond the support, fixed at one end; weights acting at two feet.

Distinguishing Number.	Species of Timber.	DEFLECTION				Weight that the Pieces broke with.			Specific Gravity.	Remarks.
		with 5 cwt.	with 10 cwt.	with 12½ cwt.	with 15 cwt.					
		ins.	ins.	ins.	ins.	cwt.	qrs.	lbs.	oz.	
1	Riga Top........	,52	1,02	2,07	3,1	16	2	0	605	All the specimens
2	— Butt......	,4	,8	1,5	2,87	18	3	0	668	in these experiments
3	— —	,37	1,0	1,37	1,62	16	1	0	821	were dry.
4	Red Pine Top....	,63	1,42	2,68		14	2	6	544	
5	—— Butt ..	,6	1,07	1,95		16	3	1	634	
6	American Spruce } Top..	,56	1,32	2,13		13	2	6	504	
7	—— Butt.	,5	,9	1,67		15	3	22	570	
8	Norway Top	,55	1,04			12	0	26	464	The butts of
9	—— Butt....	,62	1,35	1,97	3,0	16	2	12	506	these specimens
10	Adriatic Top	,5	1,0	2,0		12	3	26	467	were tough.
11	—— Butt	,4	,7	1,4		15	1	8	493	
12	Yellow 6-inch Top	,62	2,0			11	1	0	406	
13	—— Butt	,63	2,12			12	1	18	493	
14	Scotch Spruce Top	,58				9	3	16	389	
15	—— Butt	,54	2,0			10	3	26	440	The heart of pune,
16	Cowrie Top......	,37	,75	1,12	1,62	17	2	0	626	in all cases, was
17	— Butt	,5	,87	1,25	1,87	18	3	0	632	considerably weak-
18	Pune Top Outside	,46	,62	,9	1,4	18	2	14	654	er, in proportion to
19	— — Heart .	,62				9	3	18	608	the outside, than any
20	— Butt Outside	,37	,75	1,0	1,25	20	3	14	666	of the other experi-
21	— — Heart..	,57	,8			10	3	24	646	ments.

TABLE II.

Experiments on Pieces three inches square, supported on two props, at four feet distance; weights acting at the middle.

Distinguishing Number.	Species of Timber.	Deflection with 15 cwt.	What it recovered by its resilience when the weight was removed.	Deflection with 22½ cwt.	What it recovered by its resilience when the weight was removed.	Deflection after one hour's pressure with 22½ cwt.	What it recovered by its resilience when the weight was removed.	Weight that the Pieces broke with.			Specific Gravity.	Remarks.
		ins.	ins.	ins.	ins.	ins.	ins.	cwt.	qrs.	lbs.		
1	Riga Top........	,31	,29	,62	,59	,97	,91	32	2	14	664	All the pieces in these experiments were green. Most of these pieces broke off after the pressure had continued about five minutes.
2	— Butt	,25	,22	,53	,5	,85	,73	35	1	10	720	
3	Red Pine Top . . .	,81	,68	1,37	1,13	1,4	1,1	23	1	6	627	
4	—— Butt. . .	,63	,59	,95	,91	1,2	1,05	28	3	24	712	
5	American Spruce } Top..	,37	,36	,62	,6	1,87	,95	21	1	26	598	
6	—— Butt ..	,31	,29	,63	,61	1,07	,95	23	2	14	643	
7	Norway Top	,57	,50	,82	,8	1,37	,93	21	2	0	572	
8	— Butt	,58	,56	,84	,82	1,37	,95	23	1	14	595	
9	Adriatic Top	,30	,29	,42	,4			21	1	6	532	
10	—— Butt	,29	,27	,43	,41	,65	,45	23	0	16	582	
11	Yellow Pine Top .	,89	,77	1,48	1,1			21	2	0	553	
12	—— Butt	,73	,6	1,0	,9			23	3	26	661	
13	Scotch Spruce Top	,84	,83					18	2	0	478	
14	—— Butt	,72	,7					19	2	6	542	
15	Cowrie Top......	,31	,3	,43	,41	,62	,54	35	2	7	626	
16	— Butt	,31	,3	,43	,41	,62	,54	36	0	0	643	

TABLE III.

Experiments on Pieces three inches square, supported on two props, four feet distance; weights acting at the middle.

Distinguishing Number.	Species of Timber.	Deflection with 15 cwt.	What it recovered by its resilience when the weight was removed.	Deflection with 22½ cwt.	What it recovered by its resilience when the weight was removed.	Deflection after one hour's pressure.	What it recovered by its resilience when the weight was removed.	Weight that the Pieces broke with.			Specific Gravity.	Remarks.
		ins.	ins.	ins.	ins.	ins.	ins.	cwt.	qrs.	lbs.		
1	Riga Top........	,5	,48	,93	,87	1,01	,97	32	1	4	516	All the pieces in these experiments were dry.
2	— Butt	,31	,3	,62	[illegible]	,97	,85	34	1	14	633	
3	Red Pine Top....	,56	,51	1,25	1,13	1,37	1,2	23	0	0	514	
4	—— Butt ..	,42	,40	,62	[illegible]	,69	,6	25	0	0	644	
5	American Spruce } Top...	,47	,38	,91	,87	1,03	,97	22	2	26	488	
6	—— Butt..	,47	,35	,82	,78	[illegible]	,94	22	3	1	546	
7	Norway Top	,51	,49	,83	,81			21	0	14	464	Very good specimens.
8	—— Butt	,57	,56	,84	,8	1,0	,81	23	0	14	506	
9	Adriatic Top	,27	,25					21	0	26	443	
10	—— Butt	,25	,23					22	1	23	462	
11	Yellow Pine Top..	,6	,48					21	1	0	395	
12	—— Butt.	,66	,5	,99	,67	1,6	1,21	23	2	0	442	
13	Scotch Spruce Top	,75	,72					15	2	14	348	
14	—— Butt	,62	,61					17	2	0	442	
15	Cowrie Top......	[illegible]	[illegible]	,68	,64	,75	,67	32	1	0	560	
16	— Butt	,27	,27	,43	,43	,5	,48	35	1	0	582	
17	Pine Top........	,32	,32	,61	,6	,64	,62	35	2	14	632	
18	— Butt......	,25	,25	,56	,56	,62	,61	37	1	8	658	

TABLE IV.

Experiments on Pieces three inches square, supported on two props, four feet distance; weights acting at the middle.

Distinguishing Number.	Species of Timber.	Deflection with 15 cwt.	What it recovered by its resilience when the weight was removed.	Deflection with 22½ cwt.	What it recovered by its resilience when the weight was removed.	Deflection after one hour's pressure.	What it recovered by its resilience when the weight was removed.	Weight that the Pieces broke with.			Specific Gravity.	Remarks.
		ins.	ins.	ins.	ins.	ins.	ins.	cwt.	qrs.	lbs.		
1	Riga...........	,25	,25	,37	,33	,4	,33	40	1	22	610	All the pieces in these experiments were very dry, and were particularly good specimens.
2	Red Pine	,36	,35	,68	,62	,86	,78	33	3	0	544	
3	Yellow Pine......	,37	,3	,78	,72	1,0	,82	24	2	12	439	
4	Norway	,31	,3	,61	,6	,86	,63	29	1	16	517	
5	Scotch Pine	,62	,6	,93	,9			22	2	0	453	Broke after the pressure had continued fifteen minutes.
6	Cowrie	,29	,29	,46	,44	,5	,45	,36	2	22	579	

TABLE V.

Specific Gravity, Relative Strength, Flexibility, and Resilience, of the different Timber used in Mast-making.

Distinguishing Number.	Species of Timber.	Mean Specific Gravity. Green.	RELATIVE			Mean Specific Gravity. Dry.
			Strength.	Deflection.	Resilience.	
1	Riga Top	682	1000	1000	1000	576
2	— Butt........	754				656
3	Red Pine Top....	647	853	1500	980	544
4	—— Butt...	741				638
5	American Spruce Top..	627	764	1100	905	541
6	—— Butt..	678				582
7	Norway Top	595	740	1260	860	509
8	— Butt	616				520
9	Adriatic Top	552	709	864	872	467
10	—— Butt	585				493
11	Yellow Pine Top .	562	746	1520	750	430
12	——— Butt.	665				472
13	Scotch Spruce Top	475	476	1450	1100	389
14	——— Butt	536				440
15	Cowrie Top......	6[illegible]4	974	920	1086	571
16	— Butt	663				619
17	Pune Top......		1226	978	1146	632
18	— Butt......					662

The results inserted in these Tables are not taken from single experiments, but are the *mean* results of numerous experiments on the same kinds of timber. The defects common to experiment on specimens of timber, caused by the crossing of the range of fibres, or from the fibres not firmly adhering, render it necessary not only to make the experiments on large specimens, but on a great number of them, and that the pieces should be cut from different trees. For, in the experiments that were made, a piece of Riga, well charged with resin, the specific gravity 821, was found to bear only 16 cwt.; whereas a piece of yellow pine, of the same length and size, with its specific gravity 504, was found to bear 25 cwt.; a piece of red pine, likewise, with a specific gravity 527, was found to bear only 18 cwt.; while a piece of Scotch spruce, the specific gravity of which was only 450, was found to bear 25 cwt. Now, if a comparison had been drawn from these results, since the experiments were good, and the pieces, to appearance, equally good, the conclusion would have been, that the yellow pine was far superior, in respect to strength, to the Riga, and the Scotch spruce to the red pine; and the same for all the other species of wood upon which the experiments were made. A like error may likewise be fallen into, on the contrary side, in determining the relative strength by a single experiment; since a piece of Riga was found to bear 42 cwt., while a piece of yellow pine was found to bear only 12 cwt.; and a piece of red pine 33 cwt., while a piece of Scotch spruce was found to bear 9 cwt. To have taken, therefore, these results for their relative strength, or the extreme for the mean strength, would have given results contrary to what a greater number of experiments has determined; for we find the mean weight that Riga will bear will lie between 32 and 36 cwt., yellow pine between 24 and 26 cwt., red pine between 27 and 30 cwt., and Scotch spruce between 13 and 17 cwt.

From these inequalities in timber, the same incorrect conclusions, without repeated experiments, will likewise be drawn in determining the specific gravity, relative deflection, and resilience of the different timbers.

In Table V. the different timbers are placed with their relative qualities, taking the Riga at 1000; the qualities are not

deduced altogether from the experiments given in the preceding Tables, but from a regular series to determine the mean, without taking into an account the extremes that, as before stated, are to be found in most kinds of timber.

Those kinds of timber that have but little or no resin, and whose colour is of a whitish or light brown cast, and are of rather a coarse grain, (as the Adriatic, Norway, &c.) will, as they become very dry, though they maintain their strength and resilience for a considerable time, be so rigid that they will be always subject to break, by any sudden impulses, without warning, especially if they are kept in dry stores for a long time.

The Riga and other timbers containing a proper quantity of resin, and the red pine, from the fineness and closeness of its grain, and adhesiveness of its fibre, not only maintain their resilience, but strength and flexibility, much longer,—even to a very dry state.

The cowrie possesses advantages over most other timbers, from the firmness of its grain, and uniformity of its texture. In all the experiments made upon its strength, both dry and green, it was found commonly to bear 36 cwt., and never to bear less than 30 cwt.; while, at the same time, the heart appeared equally strong with the outside.

The experiments that have been made on this timber, compared with the Riga, Dantzic, and other esteemed firs, justify a conclusion that it possesses qualities equally good with these timbers, for all the purposes for which they are generally used. The cowrie, by being exposed to the weather, appears less liable to shrink, and stands equally well with them. A piece, half an inch thick and about a foot wide, with a wind-shock extending part of the way up from one end, was exposed to the vicissitudes of the weather for more than eighteen months; after which period it was no more shaken, and underwent no other alteration, than the sap that was on it to some distance from one edge disappearing, and leaving it with the colour and the firmness of the wood fully elaborated. Most of the cowrie spars that have been brought to England appear but a little beyond the saplings, since many of the full-grown trees are said to exceed thirty feet in girth, and to continue the full size to nearly sixty feet from the ground. Their common diameter is

from three to six feet, and their length frequently from ninety to one hundred feet, clear of branches.

From the experiments that have been made on the different kinds of timber employed in mast-making, and the results of which are confirmed by experience in the use of them, a fair conclusion may be drawn, that timber, whose specific gravity does not exceed that of the Riga, and whose strength, tried on pieces of the same dimensions, and under the same circumstances as those in the foregoing experiments, which is found equal to bear 24 cwt. with its flexibility and resilience, within the limits of the results in these Tables, may be considered suitable for the purposes of mast-making, as far as respects these qualities; while its durability may be judged of by close observation on the texture of its fibres, uniformity of growth, and by the quantity and state of the resinous substances it contains.

Art. IX.—*On the Position of a Body added to a Mass, in Influencing Angular Velocity.*

(*To the Editor of the Papers on Naval Architecture.*)

The following mathematical investigation is offered for insertion in your Papers on Naval Architecture, under the consideration that it may be rendered applicable, in connexion with other circumstances, to the determination of the position of the moveable weights in a ship. X.

If M be the mass of any body, m a mass small compared with M, which may be placed at any point in M, it is required to find the position of m, so that a given impact being communicated at a given point of the compound body, the initial angular velocity communicated may be a maximum.

Let AB (Fig. 3) be a section of the body M, by a plane passing through its centre of gravity G, and the direction of the impact, C the point of impact, H the required place of m. Let $CG = h$, and the radius of gyration of M round an axis passing through C perpendicular to the section $= k$, and $CH = x$.

Then $Mk^2 + mx^2 =$ moment of inertion of the compound

body round the axis passing through C. Also $\frac{M h + m x}{M + m}$ = distance of the centre of gravity of M + m from C; wherefore $M k^2 + m x^2 - (M + m) \cdot \left(\frac{M h + m x}{M - m}\right)^2$ is the moment of inertia of M + m round an axis parallel to the former, passing through their common centre of gravity, and the mass at C, to have the same moment of inertia round the same axis, is $= \frac{(M k^2 + m x^2) \cdot (M + m)^2}{(M h + m x)^2} - (M + m)$

Hence the velocity of C round an axis passing through the common centre of gravity perpendicular to the section

$$= \frac{\textit{the moment of the impact}}{\frac{(M k^2 + m x^2) \cdot (M + m)^2}{(M h + m x)^2} - (M + m)},$$

and the angular velocity round the same axis

$$= \frac{\textit{the moment of the impact}}{\frac{(M k^2 + m x^2) \cdot (M + m)}{M h + m x} - (M h + m x)},$$

which is to be a maximum; hence $\frac{M k^2 + m x^2}{M h + m x} - \frac{M h + m x}{M + m}$ must be a minimum,

$$\therefore 2 M h x + 2 m x^2 - (M k^2 + m x^2) - \frac{(M h + m x)^2}{M + m} = 0,$$

or $x^2 + \frac{2 M}{m} h x = \frac{M}{m} (k^2 + h^2) + k^2$,

and $x = \frac{M h}{m} \pm \sqrt{\frac{M^2 h^2}{m^2} + \frac{M}{m} (k^2 + h^2) + k^2}$

$$= -\frac{M h}{m} \pm \frac{M h}{m} \cdot \left(1 + \left(\frac{m}{M} \cdot \frac{k^2 + h^2}{h^2} + \frac{m^2}{M^2} \cdot \frac{k^2}{h^2}\right)\right)^{\frac{1}{2}};$$

and considering m small compared with M, and using the upper sign only as alone applicable in the present case, we have $x = \frac{1}{2} \cdot \frac{h^2 + k^2}{h} - \frac{m}{8 M} \cdot \frac{(h^2 \sim k^2)^2}{h^3}$, very nearly, and which differs little from $\frac{1}{2} \cdot \frac{h^2 + k^2}{h}$.

The reason we have considered m small compared with M, is that the space it occupies may be so small, that the distance from C to the centre of gravity of m may be the same as the distance from C to the centre of gyration of m when revolving round C.

ART. X.—*Remarks on Two Papers published in the Philosophical Transactions of* 1796 *and* 1798, *of the Royal Society of London, on the Stability of Floating Bodies, with its Application to Ships, by George Atwood, Esq., F.R.S.*

THE author of these Papers was well known for his writings on mechanical science, and particularly the excellent work on rotatory motion. The branch of naval architecture he chose for his consideration was properly within the limits of the investigations of a mathematician, unacquainted with the other parts of the science. In his first Paper he illustrates the principles of floating bodies, and determines, according to their forms and specific gravities, the manner of their floating. In his second Paper he applies these principles to the determination of the stability of ships.

Euler, Bouguer, Atwood, and others, investigated the subject on the same well-known principle of hydrostatics:—that the vertical pressure of the fluid must always be estimated as passing through the centre of gravity of the displaced volume; and that when the body is deflected from its upright position, it will either return to it, or incline further, according as the vertical pressure of the fluid acts on the immersed or emerged side of the centre of gravity of the body.

Euler, in his Treatise on the Construction and Properties of Ships, describes the stability of a vessel under the different circumstances to which it is liable. He says, (Colonel Watson's Translation,) " As soon as a vessel becomes ever so little inclined or displaced from its state of equilibrium, it is evident that three consequences may happen: 1st, Either the vessel remains in this inclined state, in which case we say the equilibrium is insensible; or, 2dly, It re-establishes itself in its preceding situation, when its equilibrium will be permanent, or, rather, it will be endowed with a stability which may be great or little, according to circumstances; or, 3dly, The vessel, after this inclination, will be overturned. An equilibrium of this kind is like to that of a needle, which, put upon its point, falls the moment it has received the least motion. This equilibrium is called unstable, or ready to fall. We see, evidently, that neither this last case

nor the first can have place in vessels; and with respect to the second case, a sufficient stability is absolutely requisite."

In the first state, the equilibrium of insensibility, the vertical mean direction of the water, when the vessel is inclined, continues to pass through its centre of gravity; in the second state, the equilibrium of instability, the mean vertical direction, when the vessel is inclined, passes on the immersed side of its centre of gravity, and thus tends to restore it to its upright position; in the third state, the equilibrium of instability, the mean vertical direction, when the vessel is inclined, passes on the emerged side of its centre of gravity, and thus causes it to incline further.

The perpendicular distance at which the vertical pressure passes from the centre of gravity of the ship, is the correct measure of the stability at every inclination. The mathematical expression, which measures the stability, involves the volume of the body immersed by the inclination, and the distance between the centres of gravity of the volumes immersed and emerged. All the French writers, and indeed all writers on naval architecture before Atwood, determined these elements under the supposition, that the transverse sections of the immersion and emersion at any angle were right-angled triangles, and that the horizontal distance between their centres of gravity was two-thirds the breadth at the line of floatation. This was the error Atwood corrected; he shows that this supposition is true only at infinitely small angles of inclination. In his own method of calculating the stability, he measured correctly these elements, by rules of approximation for the quadrature of curves and the content of solids.

By the French method of estimating the stability, a general differential expression is given, which determines the height above the centre of gravity of the ship, at which the vertical pressure of the water, when the ship is inclined, cuts the vertical axis of the ship when upright, which is called the height of the metacentre. This is the radius to which the sine of the angle of inclination is calculated, to determine the measure of the stability.

Bouguer, in his *Traité du Navire*, investigates, with great ability, the properties of the metacentre. He first determines

its height for regular bodies, and afterwards for ships. If the body were a rectangular parallelopiped, he shows that its height is determined by this proportion: three times the depth to which the body is immersed is to its half-breadth, as the half-breadth is to the height of the metacentre above the centre of gravity of displacement. If all the transverse vertical sections of the body were triangles instead of parallelograms, the height of the metacentre above the surface of the water is equal to the depth of the centre of gravity of the displacement. When these sections are similar ellipses, the height of the metacentre above the surface of the water will be found, by taking three-eighths the excess of the square of the half-breadth above the square of the depth, and dividing the product by the breadth. He then applies the metacentre to the determination of the stability of ships generally, at all inclinations.

Atwood agrees with the general reasoning on the metacentre, and even admits that it may be used at *very small angles* of inclination, with sufficient accuracy in determining the stability of ships, but does not allow its application for general practical purposes at all inclinations. He shows that two ships may have precisely the same plane of floatation, which, supposing the relative distance between the centres of gravity of the ship and of the displacement equal in both ships, will determine the height of the metacentre to be the same, and, according to the French theory, the stability consequently equal; and yet, by a difference of form within the limits of the immersion and emersion, the stability, when correctly measured, may be very different.

It is remarkable, that the stability of all ships, by the French method, would be the same, *cæteris paribus*, as if the sides between the immersion and emersion were circular arcs, and the stability correctly measured by Atwood's method.

The practical error may be, however, fairly ascertained by a comparison between the two methods subjected to actual calculation on the stability of the same vessels.

Stability, in tons, at an inclination of 10°, of the

	By Atwood's method.	By the French method.	Error.
Endymion, of 50 guns,	1729	1736	$7 = \frac{1}{247}$
Icarus, of 10 —	208	205	$3 = \frac{1}{69}$ nearly.

The errors in these examples certainly appear much less than the reasoning of Atwood would lead us to believe.

The simplicity and ease with which the French method is applied to practice, in comparison with the tedious calculations of Atwood's method, give a decided superiority to the metacentric measure of the stability, if the result may be safely relied on. Actual calculation shows that the error is small in ships of the usual forms. There is, however, danger of considerable error in the use of the metacentre by those who are unacquainted with the true method of calculating the stability. A knowledge of Atwood's method shows the necessity of examining the design within the limits of the immersion and emersion; and if the sides of the ship should be found to incline inward greatly in those parts, the metacentric method would be known to be inapplicable. To use the French method with safety, a knowledge of the true method of calculating the stability is indispensably necessary. With this knowledge, and a correct acquaintance with the drawings of a ship, a constructor will not, in ordinary cases, be liable to any considerable error by the use of the metacentric method of calculating the stability of a ship.

It must also be considered, that the method used to determine whether a ship to be built will have sufficient stability, is to compare it with the stability of a ship of the same class, that, from experience, is found to possess this quality in a proper degree; so that it is the relative, and not the absolute stability, that is generally required to be known. The absolute stability of a ship cannot be determined without finding the situation of the centre of gravity of the ship, to obtain which, by Chapman's experiment, (page 17,) it is necessary to find the stability by Atwood's method.

Atwood adduces, as a proof of the imperfection of the French method of measuring the stability, the case of Le Scipion, built at Rochefort in 1779, and L'Hercule and Le Pluton, which were built from the same design, and were found, when launched, very deficient in this important quality. The first *ingénieur constructeur* was sent from Paris to remedy the defect, and after trying an alteration in the ballast, which was found totally inadequate to correct it, he directed a doubling of timber to be

brought round the sides of the ship, from one foot to four inches in thickness, extending the whole of the ship's length, and reconciling with the curve of the body ten feet below the water's surface. This completely remedied the defect. That the stability would be increased by it, would have been equally evident, by whichever method it might have been calculated. It could not have been suggested by Atwood's method, since it was not used in France,—indeed was not known. The fault of these ships was, in a great degree, if not altogether, too sudden an inclination inward abaft the main breadth. Atwood appears to have supposed it to arise altogether from falling away too suddenly below the plane of floatation. On this rests the whole of his argument in adducing these ships as an example of the incorrectness of the French, and the correctness of his, method of determining the stability of ships. Their defect might have been clearly ascertained by subjecting the design to the determination of the height of the metacentre, which would have been found much too low.

Bouguer, however, carries the theory of the metacentre much further: he says that his theory, being duly investigated under the consideration of the angle of inclination being infinitely small, it is necessary to extend the consideration of it, to render it applicable to finite angles. He traces the metacentric curve as the ship gradually inclines from its upright position, and determines its nature; he says that if this curve rises as the ship inclines, the ship will be secure; but if the curve descends, that the ship will be insecure.

Atwood shows, most clearly, the error of this doctrine: he says, that "the construction and properties of the metacentric curve, being a subject of geometrical reasoning, considered purely as such, are liable neither to ambiguity nor error; but on what grounds these properties are applied to measure the stability of vessels, or to estimate their security from upsetting, when much inclined from the upright, is not explained by M. Bouguer, M. Clairbois, or any other author I have had an opportunity of consulting."

Atwood proves that the stability of two vessels, one of which Bouguer considers to be secure in inclining and the other insecure, is exactly equal. His reasoning on this part of the subject appears most conclusive.

His application of the general principles of the stability of floating bodies to ships, whose sides, within the limits of the immersion and emersion, are regular figures, is very useful, in developing many unexpected coincidences in the measure of their stability. His analysis is not, in all cases, so neatly conducted as it might have been.

These Papers may, on the whole, be considered as contributing, in a very considerable degree, to the improvement of the science of naval architecture in one of its most important branches,—the determination of the measure of the stability. It not only proves the inaccuracy of some parts of the theory of one of the most eminent French naval architects, but gives a method, of general application to practice, strictly correct.

M.

Art. XI.—*Dimensions and calculated Elements of several Foreign Ships.*

The following Tables contain the dimensions and calculated elements of design of several French and Dutch ships, and of one Danish corvette. The collection of such information is one of the most important means of the advancement of naval architecture, by conducing to the establishment of a theory on the sure grounds of experience. As the study of this science has been more attentively pursued, and its principles more generally known, in foreign nations than in our own country, the examination of the results at which foreign constructors have arrived, and the comparison of them with the results of calculations on English ships, may be particularly useful in future designs.

Minute details have been given of the Danish corvette, as she is about the same size as the three corvettes which have been lately made the subjects of experiment. She bore an excellent character as a sea-boat, and was a very fast sailer, for which property she was expressly constructed.

The results of the French ships have been selected on account of the good qualities of the vessels from which they have been deduced, and the eminence of their constructors. The whole of the Tables may be depended upon for their accuracy.

A TABLE OF THE DIMENSIONS AND ELEMENTS OF CONSTRUCTION OF SEVERAL FRENCH SHIPS.

NAME OF THE VESSEL	L' Egyptienne. Frigate.	La Seine, Frigate.	La Virginie, Frigate.	La Félicité, Frigate.	La Venus, Frigate.	L' Embusca Frigate.	La Barbet, Corvette.
NAME OF THE CONSTRUCTOR	Caro.	Forfait.	Sanné.	Forfait.	Sanné.	Clairbois.	Coulomb.
No. of Guns and Weight of Metal	No. 30, Pdrs. 24; No. 20, Pdrs. 8	No. 28, Pdrs. 18	No. 28, Pdrs. 18	No. 26, Pdrs. 12	No. 26, Pdrs. 12	No. 26, Pdrs. 12	No. 20, Pdrs. 8
	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
Length on the Water-Line	157,5	147,	144,	136,6	134,52	133,50	112,
Moulded Breadth	41,25	37,166	36,667	31,694	34,625	34,58	28,50
*Depth in Hold	21,75	18,	19,	17,75	17,75	17,67	14,42
Draught of Water in Midships, to the upper edge of the Rabbet of the Keel	17,25	14,	15,	13,50	13,50	13,42	11,
Height of the Midship Port from the Water	6,75	6,	6,	6,	6,	6,	5,
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
Displacement (not including the Plank) in Tons	1931,49	1311,304	1350,72	1116,257	1082,15	1095,957	603,39
Displacement before the Middle of the Length	1045,50	737,036	747,69	622,919	591,969	568,363	322,104
Displacement abaft the Middle of the Length	885,98	574,26	603,03	493,33	590,181	527,594	281,29
Proportion between the Displacement and the circumscribed Parallelopiped	,495	,483	,484	,452	,478	,498	,447
Proportion between the Midship Section and the circumscribed Parallelogram	,701	,672	,744	,742	,748	,708	,680
Proportion between the Load-water Section and the circumscribed Parallelogram	,842	,880	,815	,809	,800	,843	,801
	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
Centre of Gravity of the Displacement before the Middle of the Length	3,77	5,318	4,416	4,93	3,695	1,411	2,186
Centre of Gravity of the Displacement below the Water-Line	6,279	5,055	5,523	4,72	5,023	4,777	4,057
Metacentre above the Centre of Gravity of the Displacement	11,908	12,735	11,083	11,076	10,811	11,268	9,267
Centre of Gravity of the Midship Section below the Water-Line	6,923	3,208	6,147	4,874	5,434	5,196	4,508
Centre of Gravity of the Load-water Section before the Middle	,717	2,50	2,059	3,33	2,110	,06	,644

* The Depth in Hold, which is given in these Tables, is from a straight line drawn across the ship, at the height of the Gun-Deck at the side, to the upper edge of the Rabbet of the Keel. The Dimensions of the French and Dutch Ships are in French measure.

The water-line to which the calculations of these ships were made was drawn parallel to the keel, at the height of the mean draught of water.

This is not so correct as if all the calculations were made to the true draught of water; and the error must be considerable in those cases where a ship that sails nearly on an even keel is compared with one that has a great difference of draught of water forward and aft. The depth of the centre of gravity, and the height of the metacentre, are particularly affected by the calculations being made to this water-line. It possesses, however, on the other hand, this advantage,—that it enables a better comparison to be made of the relative fulness of the fore and after parts of the body of a ship, than when the parts of the displacement are determined to the true water-line.

Another peculiarity in the Table of French ships is the method of giving the proportion existing between the solids and the circumscribing parallelopiped, and the areas and the circumscribing parallelogram. This method is well calculated to show the relative fulness of the midship sections and water-lines of different ships, but should not prevent the absolute areas of the midship sections being also given in the Tables.

A TABLE OF THE DIMENSIONS AND OF SOME OF THE ELEMENTS OF THE CONSTRUCTION OF SEVERAL DUTCH SHIPS.

	Tromp	Juno.	Lynx.	Galathé.	Griev.	Harrick.	Vian Schooner.
Number of Guns	68	36	20	16	12	6	7
	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
Length on the Water-Line	157,29	127,27	105,32	101,81	87,77	65,83	75,16
Moulded Breadth	43,01	35,10	29,68	28,34	27,21	19,47	18,43
Depth in Hold	19,55	13,17	14,68	15,36	14,04	10,53	8,96
Draught of Water { forward	18,43	14,48	12,53	13,17	11,85	7,34	5,82
Draught of Water { abaft	19,31	15,80	14,04	14,92	14,04	8,38	6,14
Midship Section before the Middle of the Length of the Water-Line	9,87	7,95	9,58	1,19	5,27	3,51	8,46
Area of the Midship Section, in square feet	705,87	390,18	265,33	305,95	263,03	97,62	88,44
Foremost Section abaft the foremost Perpendicular, in feet	9,87	7,95	5,12	4,78	10,53	8,06	4,04
Area of the foremost Section, in square feet	154,39	78,09	68,93	66,71	51,52	19,85	16,84
Aftermost Section, afore the aftermost Perpendicular, in feet	9,87	7,95	9,18	7,00	7,00	4,23	4,04
Area of the aftermost Section, in square feet	257,27	89,88	54,42	41,78	47,48	47,12	28,87
Area of the Load-water Section, in square feet	6576,4	4124,0	2863,5	2620,5	2049,3	1119,6	1284,3
Displacement (including the Plank) in Tons	2378,28	983,25	570,5	637,75	440,08	129,	145,07

It appears, by this Table, that the form of ships' bodies, the situations of their centres of gravity, those of their centres of gravity of displacement, and other elements, are determined by the positions of a section forward, and another abaft, and the proportion which the areas of these sections bear to that of the midship section, and to each other.

This method may give some vague notion of the relative fulness of the fore and after bodies, but is altogether inadequate to determine any property of a ship with any tolerable degree of accuracy; for the two ships may agree exactly in the area of the midship section, and the positions and areas of these balance sections, and differ greatly in every property.

Principal Dimensions, &c. &c. of a Danish Corvette mounting 20 Guns, carrying Ball of 19,6*lbs. English weight.*

Draught of water forward, 12,64 feet; abaft, 14,2 feet.

Length on the water-line, 115,39 feet.

Breadth to the outside of the timbers at the midship section, 30,13 feet.

Breadth ditto at the wing transom, 18,71 feet.

Depth in hold, 15,73 feet.

Height of the midship port above the water, 5,409 feet.

Area of the midship section, in square feet, 238,82.

Centre of gravity of the midship section, 4,49 feet below the water-line.

Area of the load-water section, in square feet, 2855,57.

Centre of gravity of the load-water section, ,718 before the middle of the length.

Displacement, in cubic feet, 18825,6.

Displacement of the foremost third of the length, 5611,2 cubic feet.

Ditto of the middle third, 8865, ditto.

Ditto of the aftermost third, 4349,4 ditto.

Centre of gravity of the displacement, 2,53 feet before the middle of the water-line.

Ditto ditto, 4,13 feet below the water-line.

Height of the metacentre above the centre of gravity of the displacement, 9,401 feet.

Height of the metacentre above the water-line, 5,263 feet.

Area of the sails, 13718,9 square feet.

Height of the centre of effort of the wind on the sails, above the water-line, 46,18 feet.

Horizontal distance of the centre of effort before the centre of gravity of the ship, 5,68 feet.

Total number of the crew, 125 men, including officers.

To carry three months' provisions and stores.

The quantity of ballast, 1760 pigs, each weighing 109,09 lbs.

Fifty rounds of shot and ammunition for each gun, the charge of powder being allowed at $\frac{1}{3}$ the weight of the ball.

The weight of each gun, 16,7 cwt.

Four anchors, each weighing 1 ton 4 cwt. 3 qrs.; and two, each weighing 6 cwt. 1 qr.

DIMENSIONS OF THE MASTS AND YARDS.

Dimensions of the Masts.	Extreme Length.	Diameter.	Length of the Head.
	Feet.	Feet.	Feet.
Main	68,51	1,802	9,27
Main-top	41,47	1,03	5,41
Main-top-gallant	23,1	,501	3,09
Fore	62,33	1,717	8,24
Fore-top	38,62	,987	5,15
Fore-top-gallant	21,89	,486	3,09
Mizen	56,66	1,28	6,18
Mizen-top	32,71	,987	4,12
Mizen-top-gallant	17,25	,407	2,84
Bowsprit	43,26	{ 1,802 { 1,717	
Jib-boom	32,45	,937	

Dimensions of the Yards.	Length	Diameter.
	Feet	Feet
Main	60,78	1,22
Main-topsail	50,02	,858
Main-top-gallant	31,42	,493
Fore	55,6	1,137
Fore-topsail	45,53	,815
Fore-top-gal'ant	28,84	,458
Mizen-topsail	36,06	,657
Mizen-top-gallant	23,69	,343
Cross Jack	44,3	,773
Driver-boom	43,01	,802
Gaff	30,65	,707

The relation between the length of the water line and the distance of its middle point, abaft the centre of the foremast, is ,380.

Ditto, before the centre of the mainmast, is ,060.

Ditto, before the centre of the mizenmast, is ,340.

The whole of the results and dimensions of this corvette are reduced to English measure. C.

ART. XII.—*On the Experimental Cruises of His Majesty's Corvettes, Orestes, Champion, and Pylades.*

THE attention of all who take any interest in naval affairs was, some time since, directed to the progress and results of the experimental cruises which were undertaken to ascertain the respective merits of His Majesty's three corvettes, Orestes, Champion, and Pylades, and particularly to make trial of a new method of constructing ships' bodies, which had been proposed by Capt. Hayes, of the Royal Navy.

In March, 1823, a cutter, called the Arrow, which had been constructed by him, and built under his direction, was launched from Portsmouth Dockyard; she was tried with other cutters, and the reports which were then made of her qualities were highly favourable. The Lords of the Admiralty authorized a further trial of the system, and Captain Hayes was consequently allowed to prepare the drawing of the Champion, a corvette of 18 guns, which, it was understood, would be opposed to the Pylades, a corvette of the same class, to be constructed at the Navy Office, under the direction of Sir Robert Seppings, Surveyor of His Majesty's Navy, and to the Orestes, another of the same class, which was at the time preparing at the School of Naval Architecture, under the direction of Professor Inman.

So little being yet known of the nature and first principles of fluids, and the laws of their resistances, the theoretical study of Naval Architecture has been attended with an uncertainty tending greatly to check its progress. Those who have attempted to investigate its intricacies have undoubtedly done much, but they have still left much undone. Other sciences are continually drawing new inductions, or receiving confirmation from the results of experiments; but experiments in Naval Architecture are attended with so many difficulties, as to have deprived it in a great degree of this principal means of improvement. It would be necessary, in order to prevent too hasty, and possibly erroneous inferences being drawn, to make the conditions under which the experiments should be made so numerous, and consequently the conduct of them so expensive,

as to amount almost to an impossibility for an individual to attempt them with any prospect of considerable success.

Many experiments have, at different times, been made by means of models; but, owing to the difficulty of placing a model under similar circumstances with the vessel which it is intended to represent, the results have almost always been unsatisfactory, and frequently contradictory; their failure has also often arisen from having been made under the direction of persons not adequately acquainted with the principles they were intended to illustrate. This may lead us to the consideration that the investigation of this subject should be pursued rather by experiments on ships themselves, than on models, and is therefore rather to be viewed as a national than a private undertaking.

The very liberal manner in which the Right Honourable Board of Admiralty has directed these trials of the experimental corvettes, must be received by all who are interested in the advancement of Naval Architecture with the greatest satisfaction, as pointing out one of the proper means for its investigation, and giving a powerful impulse to its progress, which may fairly be expected to conduce to the eventual arrival at results of the greatest practical benefit to the science.

By making experiments on *ships*, the valuable experience of naval officers is brought to the assistance of the naval architect. By constant observation of the good or bad qualities of their ships, with attention to those circumstances on which the variation of those qualities depends; as to trim, ballasting, disposition of masts, yards, sails, &c. the properties of ships may be assigned to their true causes. Such information must be of the greatest assistance to the scientific constructor, who needs such a combination of knowledge to design with probable hopes of success. These observations must, of course, be made with the strictest attention to every attendant circumstance; and not till every doubt as to the correctness of the result is removed, may any inference be drawn.

The Orestes was commanded by Captain Litchfield, the Champion by Captain Studdert, and the Pylades by Captain Fead, during all the cruises.[1]

[1] The ships are mentioned in the order of seniority of their respective commanders.

PRINCIPAL DIMENSIONS.

	Orestes.		Champion.		Pylades.	
	Ft.	Ins.	Ft.	Ins.	Ft.	Ins.
Length on the Lower Deck	109	11	109	6	108	6
Length of the Keel for Tonnage	92	10⅛	91	10⅛	90	2⅞
Breadth extreme	30	6	30	6⅛	30	0¼
Breadth moulded	30	0	30	0⅛	29	6¼
Depth in Hold	7	6¾	7	8¾	8	2
Burthen, in Tons. No.	459 37/94		455 53/94		433	

RESULTS OF CALCULATIONS MADE ON THE BODIES TO THE GIVEN DRAUGHTS OF WATER.

	Orestes.		Champion.		Pylades.	
	Ft.	Ins.	Ft.	Ins.	Ft.	Ins.
Draught of Water — forward	12	6	14	6	12	4
Draught of Water — abaft	14	1	14	6	13	6
Area of the Load-Water Section, in square Feet	2827,6		2918,8		2710,42	
Distance the Centre of Gravity of the Load-Water Section is before the middle of its Length, in feet	1,0		,12		,8	
Area of the Midship Section, in square Feet	238,28		256,1		231,7	
Displacement, in Tons, to the Load-Water Section	534,25		595,0		524,32	
Distance the Centre of Gravity of the Displacement is before the Middle of the Length, in Feet	2,2		1,38		1,956	
Depth of the Centre of Gravity of the Displacement below the Load-Water Section, in Feet.	3,84		4,37		4,15	
Moment of the Stability, at an inclination of 1°, in Tons	535,7		525,5		455,	
Light draught of Water — forward	8	6	10	8	8	8¼
Light draught of Water — abaft	11	0	10	10	10	11
Displacement, in Tons, to the light Draught of Water	282,		305,		291,0	

The Pylades is rather longer in proportion to the breadth than the two other corvettes. The Orestes and Champion have their midship sections nearly coincident for a considerable distance above and below the water's surface; but the Champion has greater depth below the water; they have both a hollow from the keel to the floor-heads, but the Pylades is straight in those parts. The Orestes and Pylades were constructed to draw more water abaft than forward, but the Champion to sail on an even keel. The former two have their after-bodies fine, but the latter has hers remarkably full. The relative capacity of their fore and after bodies may be seen tolerably clearly by the following calculations, made by dividing their displacements, taken to the same draught of water, into three parts of equal length on the water line. The water lines were drawn parallel to the keel, and at a height equal to a mean of the draughts of water in midships—

	Orestes.	Champion.	Pylades.
Foremost part, in Tons..........	176,6	162,6	181,7
Midship part, in Tons	251,3	246,3	247,1
Aftermost part, in Tons	124,7	138,3	133,7

There are several differences in the practical construction of the ships, made, of course, with the intention of improving their qualities.

The Orestes has an iron keelson, and iron limber boards, which give room for stowage, and by lowering the centre of gravity of the system, increases the stability. The Champion has the sides of her keel curved, and the keel is wider at the lower side than at the rabbet; she had also three inches more false keel than the other two: this was all probably done with the intention of gaining lateral resistance when on a wind. The Pylades has only six iron knees on each side to her beams, has iron limber boards, and is filled in with cement below; all of which concur in lowering the centre of gravity, and thereby increasing the stability.

A TABLE of the Draughts of Water, Height of Ports above the Water, &c. &c. of His Majesty's Corvettes, Orestes, Champion, and Pylades, previous to their sailing on the first experimental Cruise.

	Orestes.	Champion.	Pylades.
	Ft. Ins.	Ft. Ins.	Ft. Ins.
Draught of Water, forward..........................	12 11	14 6	12 2
Draught of Water, abaft..........................	14 $1\frac{1}{2}$	14 6	13 4
Depth of Keel and false Keel below the lower edge of the Rabbet..........................	1 4	1 7	1 4
Length of the above Water-Line	110 10	110 10	107 9
Breadth of Ditto..........................	30 6	30 6	30 0
Area of the Midship Section, in square feet........	245,2	256,1	226,8
Displacement to the Water-Line, in tons..........	552,8	595,	511,3
Height of the Ports above the Water, forward	6 8	6 6	6 3
Height of the Ports above the Water, in Midship..	5 7	5 7	5 10
Height of the Ports above the Water, abaft	6 $4\frac{1}{2}$	6 5	6 8
*Area of the Sails, in square feet..................	10865,7	10941,4	10164,
Height of the Centre of Effort above the Water-Line, in feet	50,3	48,5	47,7
Distance of the Centre of Effort before the Middle of the Water-Line, in feet....................	8,77	7,9	9,4
Quantity of Ballast, in tons	43,75	49,0	30,
Number of the Crew	97	106	110
	Ins.	Ins.	Ins.
Rake of the Masts, in 12 feet, Fore	2	1	$1\frac{3}{4}$
Rake of the Masts, in 12 feet, Main..............	4	$4\frac{1}{2}$	$2\frac{7}{8}$
Rake of the Masts, in 12 feet, Mizen	8	8	$2\frac{7}{8}$
Steive of the Bowsprit, in 12 feet	5 9	4 9	4 2
Relation between the Length of the Water-Line and the Distance of its Middle Point abaft the Centre of the Fore-mast	,387	,373	,4006
Ditto, before the Centre of the Main-mast	,068	,072	,055
Ditto, before the Centre of the Mizen-mast........	,36	,357	,352

* Including Courses, Top-sails, Top-gallant-sails, Fore-top-mast Stay-sail, Jib, and Driver.

A TABLE OF THE LENGTHS AND DIAMETERS OF THE MASTS AND YARDS OF HIS MAJESTY'S THREE CORVETTES, ORESTES, CHAMPION, AND PYLADES, PREVIOUS TO THEIR SAILING ON THE FIRST EXPERIMENTAL CRUISE.

LENGTHS AND DIAMETERS OF MASTS.

	Orestes.			*Champion.*			*Pylades.*		
	Length.		Diameter.	Length.		Diameter.	Length		Diameter.
	Yds.	Ins.	Inches.	Yds.	Ins.	Inches.	Yds.	Ins.	Inches.
Main	23	0	20	23	0	22	23	12	20¼
Main-Top	14	18	12¼	14	0	13	14	12	12½
Main-Top-Gallant ..	7	30	7¼	9	0	8	7	12	7
Fore	21	6	18¼	21	0	20	21	11	18¾
Fore-Top	13	2	12½	12	0	13	12	30	12½
Fore-Top-Gallant ..	7	2	7¼	8	0	8	6	30	7
Mizen..............	19	3	16¼	20	6	17	19	12	15¾
Mizen-Top	9	21	8½	9	0	8¼	9	12	8¼
Mizen-Top-Gallant .	5	6	5⅛	6	24	5½	4	24	4⅝
Bowsprit	12	33	19¼	14	0	20	14	12	20¼
Jib-boom	11	6	9¾	11	0	10	10	24	9¼
Driver-boom.......	14	12	9	15	12	9½	14	20	9¼
Gaff................	10	21	7½	11	0	8	10	18	7¼

LENGTHS AND DIAMETERS OF YARDS.

	Orestes.			*Champion.*			*Pylades.*		
	Length.		Diameter.	Length.		Diameter.	Length.		Diameter.
	Yds.	Ins.	Inches.	Yds.	Ins.	Inches.	Yds.	Ins.	Inches.
Main	20	14	14¼	20	12	15	19	30	14⅛
Main-Topsail	15	3	9½	15	12	9½	14	10	9¼
Main-Top-Gallant ..	10	0	6¼	10	12	7	9	28	5⅝
Fore	18	23	12¼	18	0	13½	17	16	12½
Fore-Topsail	13	21	8½	13	18	8½	12	20	8½
Fore-Top-Gallant	9	0	5⅝	9	0	5½	8	24	5⅝
Mizen-Topsail	10	0	6¼	10	12	7	9	15	6¼
Mizen-Top-Gallant ..	6	24	4⅛	7	0	8	6	19	4⅛
Cross Jack	15	3	9½	15	12	9½	14	10	9¼
Spritsail	13	21	8½	13	18	8½			
Spritsail-Top-sail....	9	0	5⅝	9	0	5½			

The Tables which follow, containing the results of each day's trial, have been compiled from the accounts given in journals kept on board each ship during the cruises. The letters O, C, P, the initials of the ship's names, are taken to distinguish their respective ships; and the numbers placed between them are the distances gained by each vessel on the following one. Thus, on the 16th of October, the ships were sailing with the wind abeam; and, it appears by the Table, that the Pylades, in four hours, gained one mile to windward of the Orestes and Champion, which two ships were equal in this respect; but, that, during the same time, the Pylades had also fore-reached, or headed, the Orestes two miles and a quarter, and that ship had headed the Champion one mile. As it is extremely difficult to judge correctly as to distances at sea, the different accounts vary considerably, in consequence of which an average has been taken of the whole of them; and as four accounts have been referred to for each cruise, it is probable that a tolerably correct statement has resulted:—

A TABLE

of each Day's Sailing of His Majesty's three Corvettes, Orestes, Champion, and Pylades, during the first experimental Cruise, under the Command of Captain Wallis, of His Majesty's Ship Niemen.

Date.	Wind.	Quantity of Wind.	Distance gained to windward.	Distance gained ahead.	Duration of the trial.	Remarks and Occurrences.
			Miles. Miles.	Miles. Miles	hrs. ′	
Oct. 16th	Wind abeam.	Top-gallant breeze.	P. 1 O. = C.	P. 2¼ O. 1 C.	4 0	As the wind died away, the Pylades' relative velocity increased. The Champion asked permission to re-stow her hold.
17th	Close-hauled.	Ditto, brisk.	C. ¾ O. 5 P.	O. = P. ½ C.	4 0	There was a heavy sea, which apparently had great effect in throwing Orestes off the wind. Pylades took in top-gallant-sails for a short time.
*18th	Ditto.	Ditto, strong.	C. 1¼ O. ½ P.	P. ½ O. ½ C.	3 30	Squadron in chase of Calliope. Orestes found her main-top-mast was sprung; and Pylades asked permission to go into port, to take in ballast.
19th	—	—	—	—	—	Making for Plymouth Sound. While in the Sound, Pylades took in fifteen tons of ballast; Orestes took in ten tons of water; and Champion re-stowed her hold, and took in five tons of water.
22d	Close-hauled.	Light & variable.	C. ⅛ O. 1½ P.	C. = O. ¾ P.	6 0	The wind scarcely filled the sails.
*23d	Ditto.	Fresh breeze.	O. C. P.	P. O. C.	—	Making sail round the Algerine. Smooth water.
24th	Ditto.	Brisk top-glt. wd.	C. 1¼ O. = P.	C. 1¾ P. 1 O.	3 40	Orestes sprung her fore-top-mast; in stays.
25th	Wind aft.	Ditto.	—	C. 1¼ P.	6 0	Orestes went into Falmouth, to get a top-mast fitted.
*26th	Close-hauled.	Hard gale.	C. P.	—	—	A very heavy sea, in which Champion had the advantage. A squall obliged the two ships to run for Torbay: in scudding they were very nearly equal; whenever it moderated, Pylades had the advantage.
	Wind aft.	Ditto.	—	P. = C.	—	
27th	—	—	—	—	—	The Champion and Pylades at Torbay: the Pylades being brought, by her extra ballast, 1 ft. 7 ins. by the stern, the rakes of her main and fore-masts were increased.
28th	—	—	—	—	—	
29th	Close-hauled.	Blowing fresh.	C. 3½ P,	P. ½ C.	2 30	The Pylades took in fore and mizen top-gallant sails, which apparently caused her to keep her wind and sail better than with them set; she carried away her jib-boom soon after the commencement of the trial.
	Wind aft.	Ditto.	—	P. = C.	—	
30th	—	—	—	—	—	At Torbay.
31st	—	—	—	—	—	
Nov. 1st	Wind aft.	Top-gallant breeze.	—	O. = P. ½ C.	10 0	The Orestes and Pylades kept the Champion astern the whole day, and held way together, till Orestes sprung her mizen-top-mast, and carried away her main-top-gallant-mast; Pylades then passed her; but when Orestes got up another top gallant-mast, she again came up with Pylades. Squadron anchored at Spithead.

* The trials on the 18th and 23d being very decisive, a detailed account is given of them, as also of the trial on the 26th.

By the foregoing Table, it will be seen that the Champion proved superior to the other two corvettes, in the important quality of holding a wind; and that, in this point of sailing, the Orestes was superior to the Pylades. The latter two ships carried lee-helms generally during the cruise. The Orestes, under three top-sails, fore-sail, main try-sail, and fore-top-mast stay-sail, carried her helm nearly hard down; and the Pylades was confessedly more leewardly than the Orestes. This might, in both ships, arise from their masts being improperly placed, which was supposed to be the case, as in pitching they appeared to be overpressed with head-sail; the Orestes, under close-reefed main-top-sail, reefed fore-sail, main-try-sail, and main-stay-sail, with a hard wind and a heavy sea, plunged deeply; but when the fore-top-mast stay-sail was set, and the fore-sail taken in, she was relieved.

The positions of the masts in a ship depend on the following principle:—The situation of the mean direction of the resistance of the water against the ship should be found, and if the masts were then placed so that the centre of effort of the wind on the ship's sails were directly opposed to the mean direction of the resistance of the water, the action of neither of these forces would have any tendency to move the ship round her centre of gravity, and she would carry her helm amidships; or she might be made to carry it either a-lee or a-weather, by a corresponding adjustment of the two forces. The first thing to be found (the mean direction of the water) cannot, however, be determined in the present state of the knowledge of the resistance of fluids applied to naval architecture, at least by calculation, with any great degree of certainty. The masting of ships is consequently determined, at present, totally by experiment.

In the Orestes and Pylades the resultants of the resistance of the water were farther aft than the centres of effort of the wind on the sails; and of course it became necessary to produce an equilibrium between the forces by the use of the rudder.

The Pylades took in fifteen tons of ballast at Plymouth, with the hope of improving her weatherly qualities; but it does not appear that it had so much effect as might be expected. By giving her greater depth in the water, and rather increasing her stability, it perhaps enabled her to keep bodily more to wind-

ward; but this good effect was counteracted by the great addition which the ballast appears to have made to her difference of draught of water. When she sailed from Portsmouth, she was fourteen inches by the stern; and on the 28th of October, when she lay in Torbay, she was nineteen inches by the stern: so that it is doubtful whether the advantages compensated for the disadvantages, especially as it must also be remembered that her resistance was necessarily increased by it.

The additional ballast was placed round the main-mast, on the lower deck; could it have been placed lower, it would, of course, have been more effective, by a greater increase of her stability.

The Orestes and the Pylades were rather faster sailers than the Champion; and in light winds, especially before the extra ballast was taken on board, the Pylades was the fastest of the three. They are all reported to have been very easy in their pitching, 'scending, and rolling motions; and the Orestes and Champion were very dry, the Pylades was not so dry, nor could she carry sail with the other two; although on the 26th, in her trial with the Champion in very heavy weather, on a wind, under main-top-sail, main and fore stay-sails, and driver, and also on the same day, in scudding, under main and fore courses, and close-reefed main-top-sail, she was reported to have behaved very well.

The Orestes sprung three top-masts during the cruise, and her lower masts were reported to have worked considerably;—these were examined at Portsmouth, on her return, but were not found to be damaged, and were subsequently fitted to another ship.

The principal trials during this cruise were on the 18th and the 23d of October, of the sailing of which days the following is the detail:—

On the 18th, at 11 h. 15 m. A.M., the Calliope brig, having been brought, by a shift of wind, five or six miles to windward, the squadron was ordered to give chase. After working to windward for nearly four hours, the Champion brought the Calliope to, having weathered about a mile and a quarter on the Orestes, which ship had weathered half a mile on the Pylades. During the trial, in going about, the main and fore yards of the

Orestes locked: this accident, it was estimated, delayed her from five to seven minutes; but this, of course, was too short a time to have made a change in the ultimate result of the trial. There was a smart top-gallant breeze, and considerable sea running. The Orestes carried a lee-helm on both tacks.

On the 23d, the three ships were ordered to sail down to, and round the Algerine, a brig laying about eight miles to leeward; they were then to beat up to, and weather the Commodore. The Pylades passed the brig first, wore, and stood on the larboard tack; the Orestes hauled her wind on the starboard tack, three minutes and a half after the Pylades; and the Champion hauled her wind on the same tack, two minutes after the Orestes. The ships then beat up to resume their stations: the Orestes passed to windward of the Commodore, and hove to in station, about eight minutes before the Champion; and the Pylades passed to leeward of the Commodore about three minutes before the Champion passed to windward of him. During this trial there was a fresh breeze, with but little sea. The Commodore expressed his approbation of the behaviour of the Orestes during this day.

A probable reason for the difference in the results of these trials may be, that during this of the 23d the water was smooth. Often, when a ship is on a wind, she has a sea on her weather bow; this tends to force her head from the wind, and at the same time, by lifting her bows out of water, the stern is plunged more deeply in, and the resultant of the resistance is consequently brought further aft, which, when a ship already carries a lee-helm, is of course more sensibly felt. But it is often observed, that when a ship is on a wind, with a considerable inclination, she becomes more weatherly than before, for the inclination causes a great diminution of the lateral resistance in the after or fine parts of the body, while the bows, from their full form and roundness, do not experience a corresponding diminution; hence the resultant of the resistance is thrown more forward, and the ardency of the ship is increased.

It may also be remarked, that the Orestes, having completed her water at Plymouth, was only 14 inches by the stern, while, on the trial of the 18th, she had 18 inches difference of draught of water.

By reference to the sailing on the 24th of October, it will be seen that on that day the Champion gained more to windward of the Orestes than on any other day during the cruise, which must have been owing to a very heavy sea on the weather bow; for, with all the after-sail set, the latter ship carried a turn of lee-helm. The Pylades, although labouring under the same disadvantage as the Orestes, in being leewardly, did not suffer so much from the effect of the sea on her bow, as being much leaner forward than that ship, it had not the same power to lift her.

It is to be regretted, that both in the Orestes and the Pylades the difference of draught of water, forward and aft, was not diminished, even to the extent of bringing the ships on an even keel, if less would not have had the effect of making them sufficiently weatherly. Another thing might have been done which would have been a more certain guide to the constructors in making their alterations. It is, to have observed particularly what proportions of head and after sail were necessary to give sufficient weather-helm; taking, at the same time, the difference of the draught of water: these data, once known, the centre of effort of this proportion of sail might have been calculated, and then the positions of the masts altered, so that the centre of effort of the whole sail should be in its proper place. This process might be found useful in all cases in which the masts of a ship do not appear to be properly balanced.

On the return of the squadron to Portsmouth, the Orestes and the Pylades underwent the alterations which follow, and which the experience gained by the results and occurrences of the cruise had suggested. The Champion did not go into harbour, but was employed, during a part of the time thus occupied by them, in trying her sailing qualities in comparison with those of the Pandora, a brig of 18 guns, which had just arrived from a foreign station. The result of this trial was, that the Pandora was rather more weatherly than the Champion, and the Champion faster than the Pandora, when off the wind.

The principal alterations in the Orestes were the shifting the masts aft, and increasing the diameters of the spars.

	Ft.	Ins.		
The Fore-mast was shifted aft....	1	6,	and raked 2 ins.	in 12 feet.
The Main-mast was shifted aft....	1	3,	 6	—
The Mizen-mast was shifted aft....	2	9	 10	—

Alterations made in the Masts.				*Alterations made in the Yards.*			
	Length.		Diameter.		Length.		Diamete
	Yds.	Ins.	Inches.		Yds.	Ins.	Inches.
Main................	23	18	22	Main-Topsail........	15	8	9¾
Main-Top	14	14	13	Mizen-Topsail	10	12	5⅝
Main-Top-Gallant...	7	30	7½	Mizen-Top-Gallant ..	7	4	4¼
Fore	21	18	21	Cross-Jack	15	8	9¾
Fore-Top.,..........	12	26	13	Dilver-Boom	14	2	9
Fore-Top-Gallant....	7	2	7½				
Mizen-Top	10	29	9				
Mizen-Top-Gallant ..	5	16	5½				
Bowsprit............	13	30	21				
Jib-Boom............	11	1	9¾				

The principal alterations in the Pylades were, shifting the foremast 2 feet farther aft, and shortening it 18 inches; ten of which were cut from the keel of the mast, and the other eight gained by the removal of the mast aft. Also an additional keel, a foot in depth, was bolted to the original keel. The Champion made no alterations; but during the last cruise, while the squadron lay at Plymouth, the size of her main and fore courses were increased: the former about 300 square feet, and the latter about 150.

A TABLE of the Draughts of Water, Height of Ports above the Water, &c. &c. of His Majesty's Corvettes, Orestes, Champion, and Pylades, previous to their Sailing on the second Experimental Cruize.

	Orestes.		Champion.		Pylades.	
	Ft.	Ins.	Ft.	Ins.	Ft.	Ins.
Draught of Water .... forward	13	3¼	14	7	13	10½
Draught of Water .... abaft	14	0	14	4	14	6½
Depth of Keel and false Keel below the lower edge of the Rabbet	1	4	1	7	2	4
Area of the Midship Section, in square Feet	248,68		254,2		239,9	
Displacement to the Water Line, in Tons	563,74		591,5		513,5	
	Ft.	Ins.	Ft.	Ins.	Ft.	Ins.
Height of the Ports from the Water .... forward	6	3¼	6	6½	5	7
Height of the Ports from the Water .... in Midships	5	4½	5	8	5	5¾
Height of the Ports from the Water .... abaft	6	5½	6	7¼	6	6¼
Area of the Sails, in square Feet	11319,62		11397,8		9973,2	
Height of the Centre of Effort above the Water Line, in Feet	49,92		48,5		47,22	
Distance of the Centre of Effort before the Middle of the Water Line, in Feet	5,3		8,8		9,97	
Quantity of Ballast, in Tons	48,2		43,0		45,0	
Number of the Crew............................	132		137		136	
	Inches.		Inches.		Inches.	
Rake of the Masts, in 12 Feet.. Fore	2		1		1½	
Rake of the Masts, in 12 Feet.. Main	6		4½		6¼	
Rake of the Masts, in 12 Feet.. Mizen..........	10		8		7½	
Stieve of the Bowsprit, in 12 Feet	5	4	4	9	4	2
Relation between the Length of the Water Line, and the Distance of its Middle Point abaft the Centre of the Fore-mast	,374		,373		,386	
Ditto, before the Centre of the Main-mast........	,079		,072		,055	
Ditto, before the Centre of the Mizen-mast........	,385		,357		,352	

It has been said, that during the first cruise the Orestes and the Pylades carried lee-helms, and from the reasons which have been given for it, it appears evident that the alterations necessary to be made would be such as should either bring the centre of effort of the wind on the sails farther aft, or the resultant of the resistance of the water farther forward. In those which were made, the effect was apparently endeavoured to be produced by a combination of the two. In the Orestes the masts were removed further aft, which, with the increase of some, and the diminution of others of the spars, brought the centre of effort of the wind on the sails from 8,77 feet to 5,3 feet before the middle of the water-line, and the resultant of the resistance was brought forward, by diminishing the difference of draught of water $4\frac{1}{2}$ inches; for on the first cruise she sailed $14\frac{1}{2}$ inches by the stern, and on the second only ten inches.

Owing to the great length of the top-masts of the Orestes in the first cruise, the consequently large size of the top-sails brought a great strain upon them, while at the same time their stays and rigging could not afford them such effective support; this was more particularly the case with the fore-top-mast, owing to the great stive of the bowsprit. The stive of the bowsprit was therefore lessened, and the main and fore top-masts shortened, while, in order not to lose surface of sail, the main and mizen top-sail-yards were lengthened.

The alteration which was made in the position of the fore-mast of the Pylades, the diminishing its height, and the change in the water-line, were all probably made with the same intention as the similar alterations in the Orestes; and the addition of twelve inches to the depth of the keel intended, by giving her greater lateral resistance, to keep her bodily more up to windward.

A TABLE

of each Day's Sailing of His Majesty's Corvettes, Orestes, Champion, and Pylades, during the second experimental Cruise, under the Command of Captain Sir John Phillimore, of His Majesty's Ship Thetis.

Date.	Wind.	Quantity of Wind.	Distance gained to Windward.	Distance gained ahead.	Length of the Trial.		Time of commencement.	Remarks and Occurrences.
			Miles. Miles.	Miles. Miles.	Hrs.	Mins.	Hrs.	
Dec 16th	—	—	—	—	—		—	The squadron sailed from Spithead.
17th	By the wind.	Brisk top-glt. breeze.	O. 3 C. = P.	C. = P. 1 O.	4	0	9½ a.m.	Champion asked permission to start four tons of water, which was granted.
18th	Ditto.	Ditto.	O. ¾ C. ⅛ P.	O. ⅛ C. = P.	4	0	10½ a.m	Champion carried main try-sail, jib, and one reef out of top-sails more than Orestes and Pylades. Pylades did not set her fore-top-mast stay-sail till 12; at 30 minutes P.M. shook the reef out of her top-sails; and at the same time Orestes shook the reef out of her main and mizen top-sails.
19th	—	—	—	—	—		—	There was no trial. The squadron put into Plymouth.
29th	On the quarter.	Light winds.	—	O. ⅛ P. ⅓ C.	1	0	11½ a.m.	Champion carried larboard studding sails for some time.
30th	By the wind.	Reefed top-sail.	O. ⅛ C. ⅛ P.	All equal.	1	0	10½ a.m.	Orestes sprung her main-yard, and Pylades her jib-boom; the squadron therefore put back to Plymouth.
	Wind aft.	Ditto.	—	O. ¼ C. ½ P.	—		—	
*Jan. 2d	By the wind.	Blowing hard.	P. ½ C. ½ O.	O. 1¼ P. ½ C.	2	0	10 a.m.	A very heavy sea running; Champion carried fore-top-mast stay-sail more than the others; and at 10 h. 45 m. A.M. shook a reef out of her fore and main top-sails; Orestes did the same at 11 h. 20 m. A.M. At 12 Orestes missed stays and wore. A squall coming on, the squadron, with the exception of the Champion, bore up and shortened sail.
3d	Ditto	Top-glt. breeze.	O. ½ P. ¾ C.	P. 1 O. = C.	2	0	8½ a.m.	
	Ditto.	Brisk ditto.	O. = C.	O. 2½ C.	3	15	11½ a.m.	Pylades ordered down to leeward, to sail round the Egeria, which she did; the squadron then ran for Falmouth.
10th	Ditto.	Top-glt. breeze.	O. = P. ⅙ C.	O. = P. ¾ C.	1	15	2½ p.m.	The wind very variable.
11th	Ditto.	Ditto.	O. 1½ P. ¼ C.	O. ⅛ P. 1 C.	5	0	9½ a.m.	
12th	Wind abeam.	Moderate.	—	O. = P. 2 C.	3	30	9½ a.m.	
13th	On the quarter.	Ditto.	—	O. = P. ½ C.	2	0	11 a.m.	The squadron put into Scilly.

TABLE CONTINUED.

Jan. 15th	—	—	—	—	—		—	The squadron left Scilly.
16th	By the wind.	Hard-reefed top-sail.	P. ⅛ C. ½ O.	O. ½ P. 1⅜ C.	4	0	10 a.m.	Champion carried main try-sail, and for the greater part of the trial a reef out of the main course, and main top-sail more than the other ships. There was a very heavy sea running, into which the Champion pitched rather heavily; and the Pylades appeared very wet.
17th		Brisk top-gallant.	O. 2 P. ½ C.	C. 1 P. 2 O.	5	0	11 a.m.	Champion's lee-ports were open all day.
*18th	Ditto.	Hard gale.	O. 2 C. ½ P.	O. ½ P. ⅛ C.	5	30	11 a.m.	The ships ordered to carry all sail consistent with safety. Champion had her top-gallant masts on deck all day; the other two ships had them struck, but not down.
19th	Ditto.	Ditto.	—	—	—		—	There was no trial ordered, and the ships were under the same sail, when the Champion, by hoisting her main course, and shaking the reefs out of her top-sails, passed the Pylades, but was prevented passing the Orestes by that ship's hoisting more sail, though less than the Champion was under.
20th	Ditto.	Reefed top-sail.	O. = P. 2¼ C.	C. 1¼ O. 2½ P.	1	45	2 p.m.	Orestes and Champion had one reef out of top-sails, and Champion two reefs out of main top-sail, more than Pylades.
21st	Ditto.	Light winds.	O. = P. ½ C.	O. 6 C. 2 P.	6	0	10 a.m.	A heavy head swell, with very light winds.
22d	Ditto.	Brisk top-gallant	P. ½ C.	P. 2 C.	3	30	7½ a.m.	Orestes carried away her fore top mast, endeavouring to carry through a squall.
23d	—	—	—	—	—		—	No trial, being Sunday.
24th	On the quarter.	Moderate.	—	O. 2½ P. ½ C.	5	30	11 a.m.	The Commodore beat the whole squadron, heading the Orestes at least 2 miles.
25th	By the wind.	Brisk top-gallant	P. ½ C.	P. ½ C.	2	45	9½ a.m.	The Orestes shortened sail to set up her rigging, being at that time about equal to Pylades.
26th	—	—	—	—	—		—	An undecided trial, on account of a fog's coming on.
27th	Wind aft.	Moderate.	—	All equal.	3	0	9 a.m.	The squadron anchored at Spithead, at 8 P.M.

It appears evident, from the foregoing Table, that the alterations which were made in the Orestes and Pylades, were founded on correct principles. The Orestes, from carrying a lee-helm, now carried her helm a-weather, and ranked decidedly the first of the squadron when on a wind; at the same time maintaining the character of a fast-sailer, under all circumstances, in heavy weather, and in the lightest breezes. The Pylades, from being even more leewardly than the Orestes, was now, on a wind, frequently inferior only to that ship; and it was also found that the removal of the mast had made her much drier than she was during the first cruise.

The Champion, during the early part of the cruise, was much more weatherly than she became latterly. As her water and stores were diminished she lost this property, without gaining in velocity. By referring to the sailing of the 18th of December and the 22d of January (on which days the trials were made under similar circumstances,) it will be seen, that the Champion and Pylades were equal on the 18th; while on the 22d, the latter ship not only beat the former on a wind, but at the same time fore-reached her very considerably.

This is a very probable consequence of the peculiarity in the form of the Champion's after-body. As the principal permanent weights are obliged to be stowed aft, the decreasing weights are forward, and therefore the draught of water forward is constantly diminishing, and the resultant of the resistance drawing aft, which will of course diminish the weatherly properties.

There were two interesting trials, during this cruise, of the relative stability of the three ships: one on the 2d, and another on the 18th, of January.

The following is an account of the trials on the two days in question:—On the 2d of January the squadron weighed anchor, at 8 A.M., under courses, fore and main top-sails one reef out, mizen top-sail close-reefed, jib, and reefed spanker; the Champion and the Pylades carried their fore-top-mast stay-sail; the former in addition to the above sail, and the latter instead of her jib. It blew hard from the W.N.W., with a heavy sea running. The Champion, at 10 h. 45 m. A.M., shook a reef out of her fore and main top-sails, which the Orestes also did at

11 h. 20 m. A.M. At 12 the squadron was ordered to tack. The Orestes missed stays, and wore; the Champion and the Pylades stayed. At 20 m. P.M. a squall obliged the squadron to bear up and shorten sail, with the single exception of the Champion, which ship carried on. The squall lasted about twenty minutes; the Champion's inclination, during that time, was from 18 to 20 degrees.

On the 18th of January it blew a hard gale from the N.W. by W., with a very heavy sea running; the squadron was steering a S.W. by W. course. At 10 h. 45 m. A.M. the Commodore made signal to carry all sail consistent with safety The relative positions of the three ships were, at that time, the Champion $1\frac{3}{4}$ miles to windward of the Orestes, and three points before her beam; the Pylades $\frac{1}{3}$ of a mile to windward, and $\frac{3}{4}$ of a mile ahead of the Orestes.

The trial began under close-reefed top-sails, whole courses, inner jib, and double-reefed spanker; the quantity of sail was gradually increased by the ships as they found they could bear it; and at 2 h. 20 m. P.M. the Orestes was under double-reefed main, treble-reefed fore and mizen top-sails, whole courses, inner jib, and double-reefed spanker; the Champion, under treble-reefed top-sails, whole courses, inner jib, and double-reefed spanker; the Pylades, treble-reefed main, close-reefed fore and mizen top-sails, reefed courses, fore stay-sail, and spanker.

The squadron continued on the same tack during the trial. At 4 h. 30 m. P.M. Orestes weathered Champion, and hoisted colours; the Commodore made the recall. At 4 h. 40 m. Orestes crossed Champion's bows, and bore up. At the close of the trial the Champion was $\frac{1}{4}$ of a mile to leeward, and $\frac{1}{3}$ of a mile astern; and the Pylades $1\frac{1}{2}$ miles to leeward, and $\frac{1}{2}$ a mile ahead of the Orestes.

This trial of the 18th was, of course, one of the most decisive which took place during the cruise, as the ships began it under an order to do their utmost, and were, soon after its commencement, under nearly the same sail; also nothing was lost or gained by tacking; the result of the day was left to depend wholly on the good properties of the vessels.

The following are the principal alterations which were made in the three corvettes on their return to Portsmouth:—

In the Orestes, the mizen-mast was moved forward 12 ins. —the same height of the mast above the deck being preserved.

The foremast was raked, from the keel upwards, 2 ins. in twelve feet; the main-mast 4 ins., and the mizen-mast 9 ins., in the same distance.

Alterations in the Masts.	Length.		Diameter.
	Yds.	Ins.	Ins.
Main-top	14	2	13½
Fore-top...........	12	20	13¼
Mizen-top..........	10	6	9

Alterations in the Yards.	Length.		Diameter
	Yds.	Ins.	Ins.
Main-top-sail	16	0	9
Main-top-gallant....	10	12	6½
Fore.top-sail........	14	12	9
Fore-top-gallant	9	12	6¼

In the Champion, a poled mizen-top-mast was taken instead of a mizen-top-gallant-mast.

Alterations in the Masts.	Length.		Diameter.
	Yds.	Ins.	Ins.
Main	25	0	23
Main-top	15	12	14
Main-top-gallant....	8	0	8
Fore...............	22	12	20
Fore-top...........	14	0	13½
Mizen-top	10	0	9
Mizen-top-gallant pole	6	0	6
Bowsprit............	15	0	20½
Jib-boom	12	0	10
Driver-boom	14	0	9½
Gaff	10	0	8½

Alterations of the Yards.	Length.		Diameter.
	Yds.	Ins.	Ins.
Main	22	12	15½
Main-top-sail	17	12	10
Main top-gallant....	10	0	6½
Fore....	19	0	14
Fore-top-sail........	14	0	8¾
Fore-tep-gallant	8	18	5½
Mizen-top..........	11	0	6½
Mizen-top-gallant ..	6	18	4¾
Cross-Jack	17	12	9½
Spritsail..	14	0	8½

The alterations made in the Pylades were not considerable: an addition was made to the rakes of the main and mizen-masts, making that of the main-mast $10\frac{1}{2}$ inches in twelve feet, and that of the mizen $10\frac{3}{4}$ inches in the same distance.

The driver-boom was lengthened 5 feet; the gaff, 2 feet 6 ins; the cross-jack-yard, 3 feet 4 ins.; and the mizen top-sail-yard, 3 feet 1 ins.; while the bowsprit was shortened 2 feet.

By means of experiments which had been tried, during the course of the two foregoing cruises, to the extent the mast-wedges would admit, it had been ascertained that no alteration in the positions of the Champion's masts would prove beneficial to her. Her constructor therefore probably endeavoured to improve her, and gain velocity, by augmenting the propelling force, by an increase of the dimensions of the masts and gear,

and the consequent addition to the area of the sails. An extra quantity of ballast was taken on board, which, added to the other additional weights, brought the ship 5½ inches by the head, and of course brought the resultant of the resistance forward. By the increase and alterations of the sails, the centre of effort of the wind was also carried forward.

The Orestes made a comparatively small addition to the area of her sails, preserving the centre of effort at the same height from the water as before, but removing it farther forward by an alteration in the situation of the mizen-mast. During the last cruise, with the wind quarterly, and both spanker and main-sail set, she had carried half a turn of weather-helm; and in the gale on the night of the 17th of January, with no sail abaft the close-reefed main-top-sail, she also required half a turn, particularly during the squalls; it was consequently thought that she would bear a small diminution in this respect.

The alterations made in the Pylades, on her return from the first cruise, had not, it appeared, sufficiently increased her weatherly properties, as, during the last cruise, she still only carried her helm amidships, and often, when there was any sea, even with her spanker set, she carried it alee: she had therefore an addition to her after-sail, and an increase of rake to her masts.

A TABLE of the Draughts of Water, Height of Ports above the Water, &c. &c. of His Majesty's Corvettes, Orestes, Champion, and Pylades, previous to their sailing on the third experimental Cruise.

	Orestes.		Champion.		Pylades.	
	Ft.	Ins.	Ft.	Ins.	Ft.	Ins.
Draught of Water, forward	13	4	15	0½	13	9
Draught of Water, abaft	14	2	14	7	14	5
Depth of Keel and false Keel below the lower edge of the Rabbet	1	4	1	7	2	4
Area of the Midship Section, in square feet	251,28		265,2		236,7	
Displacement to the Water-Line, in tons	570,3		621,2		537,0	
Height of Ports above the Water, forward	6	3½	6	2	5	9
Height of Ports above the Water, in Midship	5	3½	5	3½	5	6¼
Height of Ports above the Water, abaft	6	3½	6	3½	6	6½
Area of the Sails, in square feet	11413,7		12567,3		10543,5	
Height of the Centre of Effort above the Water-Line, in feet	49,9		51,72		47,15	
Distance of the Centre of Effort before the Middle of the Water-Line, in feet	6,43		10,66		8,14	
Quantity of Ballast, in tons	48,2		53,0		45,0	
Number of the Crew	132		130		130	
		Ins.		Ins.		Ins.
Rake of the Masts in 12 feet, Fore		2		1		1¾
Rake of the Masts in 12 feet, Main		4		4½		10½
Rake of the Masts in 12 feet, Mizen		9		8		10¼
Steive of the Bowsprit in 12 feet	5	4	4	9	4	2
Relation between the Length of the Water-Line and the Distance of its Middle Point abaft the Centre of the Fore-Mast		,374		,373		,386
Ditto, before the Centre of the Main-Mast		,079		,072		,055
Ditto, before the Centre of the Mizen-Mast		,374		,357		,352

A TABLE

Of each day's Sailing of His Majesty's Three Corvettes, Orestes, Champion, and Pylades, during the third Experimental Cruise; under the Command of Captain Sturt, of His Majesty's Ship Phaeton.

Date.	Wind.	Quantity of Wind.	Distance gained to Windward.	Distance gained a-head.	Duration of the Trial.	Time of its commencement.	Remarks and Occurrences.
			Miles. Miles.	Miles. Miles.	Hs. Ms.	Hrs.	
Mar. 21st	By the wind.	Light winds.	P. O. C.	—	—	—	The Squadron sailed from Spithead. Pylades had considerable advantage over the Orestes and Champion.
22d	Aft, and on the Quarter.	Brisk top-gallant	—	O. 1⅓ C. 2¼ P.	6 30	10¾ a.m.	With the wind aft, all three were nearly equal; but when it quartered, the Orestes gained fast on the others.
23d	Ditto.	Ditto.	—	O. ¼ C. ⅝ P.	8 0	9½ a.m.	Champion carried main course more than Orestes, and Spanker more than Pylades.
24th	By the wind.	Reefed Topsail.	C. 1⅓ O. ¾ P.	C. 2 O. 1 P.	9 0	9 a.m.	Champion and Pylades carried the same sail. Orestes carried fore-top-gallant-sail, and one reef out of the main-top-sail less than the other two ships; she appeared to pitch more suddenly than during the former Cruises. 6 inches of the fore-stay were slacked off.
25th	Ditto. Ditto.	Hard ditto. Ditto.	P. ½ O. = C. O. = P.	P. = C. ½ O. O. = P.	4 0 —	10¼ a.m. —	A very heavy head sea, under the effects of which the Champion appeared to labour; and at 2 15 p. m. she shortened sail to set up her rigging. The Orestes carried two reefs more in the driver than Champion and Pylades, and only carried her fore-top gallant-sail for about an hour; Pylades also did not set this sail till 12.
26th	—	Blowing hard.	—	—	—	—	There was no trial. The Orestes was not so easy in her motions as during the last Cruise, which was attributed to the extreme tightness of the lower standing rigging.
27th	By the wind.	Fresh top-gallant	P. 1½ O.	O. 3½ P.	5 30	10¼ a.m.	Champion declined the trial in consequence of the bad state of her rigging.
28th	Ditto.	Light breeze.	—	—	—	—	Pylades fired two broadsides while in stays. Orestes slacked the fore-stay a little.

TABLE CONTINUED.

29th	—	Calm.	—	—	—	—	No trial.
30th	—	—	—	—	—	—	No trial.
31st	By the wind.	Strong wind.	P. 3¼ O	O. 2 P.	5¾ 20	9¾a.m.	Champion could not try, her topmast-rigging being slack. At 3 p. m. Pylades set top-gallant-sails; and at 4 p. m. carried away fore-top-most and top-gallant-mast.
April 1st	Ditto.	Hard reefed topsail.	O. ⅞ C.	O. 5¼ ¼C.	7 15	10¾a.m	Pylades employed clearing the wreck. After the trial, the Champion made signal complaining of the slackness of her rigging. The Orestes carried fore-top-mast-stay-sail instead of jib, and fore-top-gallant sail more than Champion.
2d	Ditto.	Brisk top-gallant.	C. ⅛ O. 1½ P.	P. 1 O. 1⅜ C	4 20	8¾a.m	Champion and Pylades carried the same sail. Orestes carried fore-top-mast-stay-sail instead of a jib. The squadron put into Scilly: while laying there the stays and rigging of the Orestes were slacked.
6th	—	—	—	—	—	—	No trial.
7th	By the wind. Ditto.	Brisk top-sail. Ditto.	O. = P. 1 C. P. 3½ O. ¾C.	O. 3½ P. 1½C. O. 2½ P. 1 C.	8 45 11 15	8 a.m. Ditto.	These distances are given at 4 45 p. m., when a change of wind took place, which altered the relative positions of the ships. At 7 15 the trial ended, and then the relative positions of the vessels were as given in the second distances. The correct trial should end at 4 45.
8th	Ditto.	Brisk top-gallant	P. ⅓ O. 1⅞ C.	C. 2⅝ P. ⅝O.	10 30	8½ am.	This was not at all a decided trial, as the ships alternately benefited by the weather tide, which was running in shore.
9th	—	—	—	—	—	—	No trial.
10th	—	—	—	—	—	—	No trial.
11th	—	—	—	—	—	—	Squadron anchored at Spithead.

The Phaeton, which was the Commodore's ship, had her mainmast and bowsprit hollow cylinders of iron, which were fitted on board for the purpose of experiment. The bowsprit was sprung on the 25th, and the mast on the 26th. This prevented the Commodore's taking so active a superintendance of the trials as was desirable, as it incapacitated him for carrying sail; but although the results of the cruise were, from this circumstance, not so decisive as the former ones, the progress was very interesting. The Orestes in this cruise lost the superiority she had maintained during the last.

On the 24th, under double-reefed-topsails, courses, spanker, and outer-jib, with an inclination of 12 degrees, she carried her helm amidships. A ton and a half of ballast was then moved from under the cabin to the square of the fore-hatchway, and, at the same time, the main-stay was slacked six inches; these two things made an alteration in the helm to a spoke and a half a-weather; and the next day, under courses, close-reefed topsails, jib, and double-reefed spanker with the tack up, she carried her helm three spokes a-weather, there being less sea. On the 27th, another ton was moved to the fore-bulk-head of the hold from the Captain's store-room. On the 28th the fore-stay was slacked, and on the 29th another ton and a half of ballast was moved forward; but on the trial of the 31st, under jib, courses, reefed-spanker, reefed-main, and double-reefed fore and mizen-topsails, with an inclination of 14 degrees, she was found to carry half a turn of weather-helm, consequently the last moved ton and a half was replaced in the Captain's store-room, the shot boxes were shifted from the after part of the fore-hatchway, to the cable-tier; and the boatswain's store-room was cleared of all the heavy rope, which was stowed in the square of the main-hatchway. The ship was now found to be considerably improved; and as, although there were still $2\frac{1}{2}$ tons of ballast, which had been moved forward, a great deal of heavy weight had been moved aft, consequently the slacking the main and fore-stays must have had a great part of the effect. This was the opinion on board; and, therefore, while the squadron lay at Scilly, the lower rigging was slacked, and the main and mizen-masts brought to the rake they had during the second cruise, by which the Orestes was extremely improved.

The Champion's sails were increased by the alterations between a ninth and a tenth more than she carried in the second cruise, and the centre of effort was not only raised 3,2 feet in height; but, in consequence of the extra ballast and weights which this obliged her to take on board, was also carried 1,86 feet farther forward, which made her pitching motions much more heavy. So very greatly was this ill result of her large masts felt, from the strain they brought on the rigging, that on many occasions, especially in the heaviest weather, as may be seen by the Table, she could not venture on trial with the other ships; and it does not appear that her velocity was much, if at all, increased by her addition of sail.

The Pylades, with no other alteration than a removal aft of 1,8 feet of the centre of effort, which was principally effected by the addition to the rake of the masts, was found to answer extremely well under almost all circumstances, and was much drier than in either of the other cruises.

Now, by taking in each cruise only those days on which all the three ships were on trial, and for each day giving them numbers which are inversely as the order of merit; that is, three to the first ship, two to the second, and one to the last; and if two ships were equal, and the third inferior, giving the two which were on an equality three each, and the inferior only one; and if two ships were equal and the third superior, giving this three, and the others two each, the following will be a comparative statement of the order of merit of the ships:—

TOTALS of Numbers given according to the positions of the Corvettes to windward of each other.

	1st Cruise.	2d Cruise.	3d Cruise.	Total.
Orestes	13	32	15	60
Champion	16	18	12	46
Pylades	9	26	17	52

TOTALS of Numbers given according to the positions of the Corvettes a-head of each other.

	1st Cruise.	2d Cruise.	3d Cruise.	Total.
Orestes	16	42	18	76
Champion	11	26	16	53
Pylades	18	34	15	67

Now, as when ships are close hauled, three miles gained a-head are generally considered equal to one mile gained in the direction of the wind, the numbers may be taken in the same proportion; that is, $\frac{1}{3}$ the numbers given for velocity, added to the numbers given for weatherly properties. Where this gives fractions, the nearest whole number may be taken.

Then the total number for each ship will be—

Orestes, 85; Champion, 64; Pylades, 74.

But these numbers do not give a fair comparison between the ships, in consequence of the different lengths of the cruises; this would not be of importance were it not for the consideration that in each cruise there was one ship which appeared to take the lead. And, therefore, by taking a greater number of trials in one cruise than in another, an advantage is given to some one ship: it will hence be more correct to take an equal number of trials in each cruise; and as the first was the shortest, to regulate the number by that.

TOTALS of Numbers given according to the positions of the Corvettes to windward of each other, in the first six trials of each Cruise.

	1st Cruise.	2d Cruise.	3d Cruise.	Total.
Orestes	13	16	12	41
Champion	16	10	11	37
Pylades	9	12	14	35

TOTALS of Numbers given according to the positions of the Corvettes a-head of each other in the first seven trials of each Cruise.

	1st Cruise.	2d Cruise.	3d Cruise.	Total.
Orestes	16	18	17	51
Champion	11	12	13	36
Pylades	18	16	13	47

Now, by proceeding as in the other case, the total numbers for the ships will be—

Orestes, 58; Champion, 49; Pylades, 51.

From these Tables, and the preceding statements of the different trials, a fair judgment may be formed of the relative sailing qualities of the three corvettes. In the first cruise, the Champion proved superior to the other two; in the second, the Orestes; and in the third, the Pylades. By taking the average

of the three cruises, the Orestes stands first, the Pylades second, and the Champion third.

As men of war however, other qualities of equal importance with fast sailing, must be considered, in forming a correct opinion of their relative excellencies. Stowage, accommodation, stability, and easy motion in rolling and pitching, must each be properly estimated. The best combination of all these qualities constitutes the best ship; and no quality must be considered, if the disposition of any of the elements of the construction made to insure it, is attended with a sacrifice in other important properties.

From the data in the different Tables it is seen, that the Champion had greater capacity than the Orestes, and the Orestes than the Pylades; but the Orestes was fully capable of carrying the establishment of stores appointed for this class, and the greater capacity of the Champion was principally caused by a fulness in the after-body, which required the whole of the ballast to be stowed aft, in order to bring her to her proper trim; by which a strain was brought on this part of the ship, tending greatly to weaken the structure. Though the stowage of the Pylades was inferior to that of either of the other two ships it was not subject to the ill effects likely to arise from the peculiarity of the stowage of the Champion.

With respect to the accommodations for the officers and ship's company, the Champion's were superior to the Orestes' in the size of the cabins, but attended with the disadvantages which have just been mentioned; and the Orestes afforded equal to, or rather superior accommodation than, the Champion for the ship's company. The Pylades was inferior to both the others in this respect. The following Table shows the space on the lower decks of the three ships :—

	Before the middle of the length.	Abaft the middle of the length.	Total.
	Square Feet.	Square Feet.	Square Feet.
Orestes	1290,30	1124,08	2414,38
Champion......	,1270,56	1243,60	2514,15
Pylades	1215,52	1056,22	2271.74

In rolling they were all considered easy. In pitching, the Orestes and Champion were easy and dry; the Pylades easy, but not so dry as the two others.

The Orestes and Champion were nearly equal in stability; the Pylades had not so much as either of these two, but was not at all deficient in comparison with other ships. But the peculiarity in the Champion's construction materially affected the permanence of her stability: she required her ballast to be stowed aft, consequently its centre of gravity was much higher than it would otherwise have been; and as the consumable parts of the stores were diminished, this had a proportionally greater effect in raising the centre of gravity of the system, and therefore diminishing the stability.

On the whole, then, the great fullness of the after body of the Champion was certainly a considerable fault in her construction; in the Pylades, the stowage and accommodations were small; and the Orestes might probably have been improved had her bow been rather finer. Their general excellence was established by their beating every ship that was tried with them in the cruises, with the exception of the Thetis and Phaeton, which were superior to them when sailing off the wind. C.

ART. XIII.—*Remarks on 'A Letter addressed to the Right Honourable the Earl of Liverpool, K.G. &c. &c. President of the Ship-owners' Society, on the Build and Admeasurement for Tonnage of Merchant Ships.'*

THE improvement of the forms of the Merchant Navy has been neglected to a degree scarcely to be accounted for, when considered in its immediate connexion with the interests of our merchants and ship-owners, whose enterprising and enlightened spirit on commercial affairs entitles them to the highest respect. By examining the forms of the bodies of most of our merchant ships, we find them to have been designed with the least possible attention to science. It might have been supposed, that the immense losses that were continually sustained in merchandise and shipping, would have suggested alterations in their forms, to endeavour to render the ships better able to contend with the dangers to which they were exposed; but in

this instance, experience was neglected, and centuries passed on without any considerable improvements in the forms of our merchant navy.

The author of this letter, who is an officer in the Royal Navy, appears fully sensible of the importance of this subject; and mentions, with great satisfaction, some very superior ships that have lately been built at Liverpool, and anticipates the improvement of form becoming general.

Chapman, the great Swedish writer on naval architecture, paid great attention to the design of merchant ships, and published a very valuable work, "*Architectura Navalis Mercatoria*," containing the drawings of merchant vessels of all sizes, and gave a description of them in the 11th Chapter[1] of his Treatise on ship-building. The expense and scarcity of this work have prevented its being so generally known as it deserves. He published also tables of the dimensions of merchant ships, adapted to different services, and of different sizes.

In his remarks on merchant vessels he mentions the following four qualities, which a merchant vessel ought to possess:—

1. To be able to carry a great lading in proportion to its size.

2. To sail well by the wind, in order to beat easily off a coast, where it may be embayed, and also to come about well in a hollow sea.

3. To work with a crew small in number in proportion to its cargo.

4. To be able to sail with a small quantity of ballast[2]

For a vessel to possess all these properties in an eminent degree is impossible; the form that would conduce to great excellency in one would in many cases lead to inferiority in another. The fault the author of this Letter finds with the present general form of merchant ships, is '*too great a sacrifice of expedition for burthen*;'—it may also be added, and too great a sacrifice of safety for burthen. Very few merchant

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[1] This Chapter was omitted in the translation by M. Vial Clairbois; so that it is to be found at present only in the Swedish work.

[2] English Translation, by the Rev. Doctor Inman, Professor of the Royal Naval College and School of Naval Architecture, in Portsmouth Dockyard.

vessels are so constructed as to beat well off a lee shore; as it would require a form, not the best calculated for stowage.

Chapman observes, that a merchant vessel should combine these four properties in such a manner, "that the expression representing the velocity and quantity of lading, divided by the number of the crew and quantity of ballast, may be a maximum." He says also, with still greater propriety, that "as certain commercial speculations require one quality in preference to another; the nature of the commerce; the latitudes in which it is necessary to navigate; the ports for anchorage; all these must be considered in determining which of these qualities ought to prevail, without altering in any respect the size of the ship."

The author of this letter attributes to the present mode of calculating the tonnage, the improper form given to merchant vessels, by leading the ship-owner to give small relative breadth, in order to enable the vessel to carry more than her computed tonnage. It is certainly to be regretted, that the mode of calculating the tonnage admits of such an evasion. Should the rate of duties have been fixed under the consideration of their being paid correctly in proportion to the true quantity of lading, the receipts must suffer by this evasion; but should the rate have been fixed with the understanding that the true lading is generally greater than the computed tonnage by which the dues are paid, the rate of dues per ton might be reduced in the inverse ratio of the computed to the real tonnage, and the same amount be collected, if the real and computed tonnage were made to agree by the adoption of a correct method of calculating it.

The tonnage of a ship is determined according to the common rule of multiplying the length [1] of the ship by half the

[1] This length is determined by subtracting from the length of the ship taken at a given height, an allowance for the rake of the stem and sternport. The quantity subtracted for the rake of the sternport is given in proportion to the breadth; which, not being in any way connected with it, admits of the absurdity of a ship's relative dimensions being determined so as to measure by this rule less than nothing. This would, however, only be at relative dimensions, far without the limits of practicable design. The tonnage by this rule increases as the breadth increases, till it becomes a maximum when the breadth is a little greater than the length.

square of the breadth, and dividing by 94; the quotient is the number of tons, according to which the ship is rated. This rule is agreeable to an act of Geo. 3, cap. 60.

It is evident that this rule is not founded on the true elements that enter into the consideration of the lading a ship can carry; the depth between the light and load draughts of water is totally omitted, and the half breadth substituted in its place. The difficulty of altering this rule, so as to give another of general and easy application, has been the cause of its remaining as at present. At some future opportunity we may examine some of the methods that have been proposed for measuring the tonnage more correctly. Should the present method be the hinderance to improvement in the forms of the merchant navy, it would certainly be a most powerful reason to change it, if not for one perfectly correct, at least for one not possessing this most serious fault.

The object of the author of this Letter is to point out the advantages of *increasing the breadth* of merchant ships, by which he considers the form would be generally greatly improved, as it would admit of the body below the water's surface being made much finer, without so great a loss in the lading as would be caused in a narrower ship.

He endeavours to show that such improvements would be to the interests of the ship-owner, the merchant, the underwriter, and the country. These interests are proved by the greater safety and greater expedition that would result from them.

Should the present mode of measuring the tonnage remain as at present, the advantages of improving the forms of merchant ships may yet be shown to be very great. The reduction that would arise in the loss of ships and merchandise, the lower rate of insurance that would consequently be taken, and the quicker return that would arise from the more expeditious conveyance of merchandise, would be advantages that would more than counterbalance the possibility of the evasion of dues, and the saving in building a ship at an equal expense to carry more lading than another.

It is not improbable that the present mode of estimating the

tonnage of ships may have had the effect of retarding the improvement of the forms of the merchant navy; but a more enlarged view of the subject may yet show the ship-owner the advantage of combining greater *safety* and *expedition* with stowage in the design of their bodies.

The author of this Letter considers the Royal Navy as also requiring an increase of breadth, as necessary to any great improvement in their form. After accounting, by the present mode of estimating the tonnage, "for the peculiar burthensome build of our merchant ships," he adds, "but it is more difficult to discover the cause of our inferiority with respect to men-of-war; I can only suppose that our original builders in the King's yards having served their time in merchants' yards, or gained their information by building vessels of a certain form, did not divest themselves of the notions they had received, when called upon to build for a different purpose; and this is the more plausible, as our men-of-war and merchant ships have generally the same principal fault—viz. want of breadth of beam."

This is entering on a much more difficult subject than the improvement of the merchant navy, which is certainly at a very great distance in point of excellency of form from the Royal Navy. The present proportion of the length to the breadth in His Majesty's ships, is certainly not owing to any connexion whatever between the surveyors of His Majesty's navy, who design them, and the merchant service; but must be founded entirely on their experience and judgment. Increasing the breadth of a ship within the limits of the parts immersed and emerged by inclination, certainly adds to the stability, and has been found beneficial in many instances, and may probably be tried with advantage in many others. But it must not be forgotten, that the proportion of the ships of the Royal Navy is very different from that of the merchant navy: and that there would be necessarily great disadvantage attending an excess beyond certain limits, which, although not indisputably settled, have been approximated to with considerable correctness. If the breadth of ships were too much increased, it would render them exceedingly laboursome at sea, and might unfit

them for service, by frequently carrying away their masts. Perhaps, endeavouring to avoid this very serious error, has kept this dimension rather within the limits to which it may be carried with safety and propriety. The proportion of some of the best ships of the line, both Foreign and English, is between the limits of 3,7 and 3,8 the breadth, for the length.

Increasing the dimensions of His Majesty's ships generally, the *length*, as well as the breadth, has been recommended by many, which would certainly contribute to fineness of form, as well as to good quarters; but it may be considered, at the same time, that great length is disadvantageous in other respects, in rendering ships less easily and quickly worked, and being more expensive in construction ; and, it must be remembered, that one of the greatest Admirals England has had to boast of, preferred short ships for general purposes, which he found to possess great advantages in action. Some nations have found it advantageous to build ships expressly for particular services, especially for fast sailing. In such cases great length and breadth have been given very beneficially; but, for general service, ships that can keep the sea for a long time, and under all circumstances, have been found the most efficient, even if attended with a small sacrifice of velocity, to those qualities, that especially constitute good sea-boats.

The breadths of the large ships of the English navy should probably not be increased much, while smaller ships may be increased with advantage in a greater degree.

The remarks in this Letter may, on the whole, be considered very important, particularly to the merchant navy, the improvement of whose forms may be expected chiefly from an increase of breadth.

The author has, in some cases, spoken with less respect of the science of naval architecture than it deserves, arising from considering experience as rather opposed to than combined with the theory. A theory, unconnected with experience, may indeed be considered as at best but uncertain; but, at the same time, mere experience, without science, is subject to still more dangerous errors, from frequently mistaking the principles on which the different qualities depend,

and being likely to attribute these qualities to wrong causes. It must, as before said, be by a combination of experience and a correct knowledge of scientific principles, that the true theory of naval architecture will be established. M.

Art. XIV.—*Observations on the Effect produced by Iron Masts, &c. on the Compass Needle; with an Account of an Experiment made to ascertain the Local Attraction of H. M. Ship Phaeton, (Capt. Sturt,) fitted with an Iron Main-Mast and Bowsprit. By* Mr. J. Bennett, *Naval Architect.*

In considering the rapid improvements which have been made in the arts during the present age, we cannot but reflect how much they are indebted for their progress to the general introduction of iron. While its great advantages have been acknowledged by the engineer and civil architect, in the construction of bridges, theatres, churches, &c., it has been duly appreciated by the naval architect, in its application to the building and equipment of ships. Ballast of cast iron is now substituted for shingle; wooden casks are replaced by iron tanks; and the immense consumption of valuable timber, for the purposes of hanging and lodging knees, is avoided by the general introduction of iron knees; chain cables have been partially substituted for those of hemp; iron has also been applied, in the merchant service, for beams, rigging, blocks, &c.; and even vessels of considerable burden have been entirely composed of this material.

Seeing its advantages in these respects, Mr. Bill recommended its adoption, for masts and bowsprits, in the British navy; and having submitted his plan to the Admiralty, their Lordships were pleased to order the Phaeton, a frigate of 46 guns, commanded by Captain Sturt, to be fitted with an iron main-mast and bowsprit.

This novel and ingenious application of iron has excited

considerable interest, particularly among naval officers. It is not the object of the present paper to consider the merits of the plan; we will therefore merely observe, that the experiment did not answer the inventor's expectation, as the bowsprit was carried overboard, (although it had previously encountered rather severe weather,) and it was found necessary to shift the mast, on account of symptoms of weakness.

Besides many considerations that would arise respecting its strength, elasticity, &c. it would naturally occur to every scientific inquirer, that the iron mast would have considerable effect on the compass; with this impression, Sir Byam Martin requested Mr. Barlow's opinion on the subject, which is detailed in his "Essay on Magnetic Attractions," second edition.

Till within these few years, the science of magnetism consisted but of a few detached facts, unsupported by principle, and unconnected by well-grounded theory. The experiments made by different philosophers, with the conclusions drawn from them, were extremely contradictory; but in the year 1819 a series of experiments was commenced, by one of our own countrymen, on a very extensive scale; the apparatus employed was of the most accurate description, and results the most satisfactory have followed.

Means which at first appear simple and insignificant, have ultimately developed very valuable results. Professor Barlow began his investigations by noticing the effect of a small iron ball on the needle, referring the position of the ball, as it regards latitude, longitude, and distance, to an ideal sphere circumscribing it; from this he proceeded to balls and shells of greater magnitude; and, lastly, to a gun weighing 58 cwt. By thus avoiding "a philosophy built upon speculation only, without experiment," and steadily pursuing that careful system of philosophic induction so strongly recommended by Lord Bacon, Mr. Barlow succeeded in deducing certain laws, by subjecting the results of his experiments to the dominion of analysis; generally verifying the important conclusions of Biot, Poisson, and other eminent foreign philosophers. The above experiments suggested to Mr. Barlow his method of correcting

the local attraction in vessels,[1] which consists in placing a circular plate of iron at such a distance abaft the compass that it neutralizes the influence of the iron of the ship before the compass; the smallness of the surface of the iron plate compensating, by its nearness, for the united effect of all the other iron (in the common centre of attraction) placed farther from the compass.

The effect of vertical iron became a subject of further inquiry; and the Phaeton being fitted with an iron main-mast and bowsprit, the Navy Board ordered her local attraction to be ascertained.

Philosophers had long been aware that vertical iron acquired polarity. Dr. Gilbert, who wrote on magnetism in the year 1600, discovered that the axle of the weathercock of the church at Mantua was strongly magnetic; but this property was not decidedly put to the test of experiment on board ship till the year 1822, when it was found that the local attraction of H. M. ship Leven exceeded 7°, which must chiefly be attributed to the iron spindle of Captain Phillip's patent capstan, as the local attraction of the same ship in 1820, without the capstan, was only 2° 51′. Now, supposing the quantity and distribution of the iron, as also the situation of the compass to have been the same in each case, we can form a correct estimate of the effect due to a vertical piece of iron eleven feet long, whose mean diameter was five inches, which was about the dimensions of the spindle. We cannot, however, form the same estimate of the influence of the iron mast, as the local attraction of the Phaeton was not ascertained, except with the mast on board.

The mast consists of hollow cylinders of wrought iron, $\frac{1}{4}$ inch thick and 3 feet 6 inches long, placed end to end, and connected together by iron clasp hoops, rivetted to the upper end of one

[1] It is an extraordinary circumstance, that there is no authentic record before the time of Captain Cook, which notices the effect of a ship's iron on the needle, it being first observed by Mr. Wales, his astronomer. So little, indeed, was known on the subject, that it is asserted in a scientific work of reputation (Mathematical Recreations, edited by Dr. Hutton), that the cannon and other iron have no sensible effect on the needle. This may, however, be partly accounted for, from iron not being so generally used in ships at that period as the present.

cylinder and the lower end of the adjacent cylinder, the middle of the hoop coinciding with the joint; to give additional rigidity, a clasp hoop is also rivetted in the middle of the length of each cylinder. The formation of the bowsprit differs from the above in this particular, that the cylinders overrun each other half their length. The length of the mast was 92 feet 6 inches; its mean diameter was 2 feet. The length of the bowsprit was 54 feet 6 inches; its mean diameter was $19\frac{1}{2}$ inches. The horizontal distance of the centre of the mast from the pivot of the needle was 30 feet 6 inches. The horizontal distance of the heel of the bowsprit from the needle was 98 feet 6 inches.

The situation selected by Captain Sturt and his officers, for the azimuth compass, to which the correcting plate was to be attached, was on the quarter-deck, in midships, just abaft the after ladder-way, before the steering wheel; a pedestal was placed in this spot, and the compass employed in taking the observations was put on the pedestal, which was about seven feet high from the deck, being sufficiently high to overlook the hammocks when stowed in their places.

There are two methods of ascertaining the local attraction: the first, by taking the bearings of a distant object from the compass on board; the second, by employing two compasses, one on board and the other on shore, and taking simultaneous observations at each as the ship is warped round. If we suppose a vertical axis to pass through the pivot of the needle, and the ship to revolve round this axis, the former method would be correct in principle; but as this is not practicable, an error arises from the parallax of the object, which increases with the length of the cable, the length of the ship (or, rather, the distance of the stem from the compass), and the nearness of the object. This error does not vanish, unless we suppose the distance of the object infinite; for these reasons, the latter method was preferred.

The observer on shore stood near the flag-staff at Southsea Castle, which served as an object to take the observations from the ship; whilst the reverse bearings, or those taken on shore, were referred to the mizen-mast, which was a conspicuous object, and, as it was not far from the pedestal, was sufficiently

correct. It was previously ascertained, that no guns or other iron was in the immediate vicinity of the flag-staff.

These arrangements having been made, the ship was warped round to every point of the compass. When her head was nearly in the direction of a point, the ensign was dipped, as a signal for the observer on shore to be on the look-out; and immediately the ship's head arrived at the point, the ensign was hoisted; at this instant the two bearings were taken and registered. Had there been no iron in the ship, these bearings would of course have been diametrically opposite to each other: hence their difference is the deviation of the needle from the magnetic meridian produced by the iron on board.

Considerable inconvenience was experienced from the ship being so far from the castle, (nearly two miles,) as the weather was hazy; and although the object was clearly discernible with the naked eye, it was difficult to be seen through the sight fixed to the compass. There was also a liability to inaccuracy, from considering that a small object near the eye subtends a considerable angle. Thus, when the shrouds came in the line of sight, not only was the flag-staff entirely obscured, but even the tower of the castle was partially hidden. It is therefore advisable, in experiments of this nature, when reverse bearings are taken, to have the ship as near the object as she can conveniently be brought.

Results of an Experiment on His Majesty's Ship Phaeton, (Captain Sturt,) when lying at Spithead, in order to ascertain her Local Attraction, on February 19th and 21st, 1825.

Direction of Ship's Head.	Bearing of Shore Station from Ship.		Bearing of Ship from Shore Station.		Difference of Bearings, or Local Attraction.		
FEBRUARY 19th, 1825.							
E. b. S.	N.52°	20′E.	S.53°	10′W.	—	0°	50′
East.	52	0	52	30	—	0	30
E. b. N.	51	10	52	20	—	1	10
N. E.	51	0	52	10	—	1	10
N. E. b. N.	51	40	52	10	—	0	30
N. N. E.	51	50	52	0	—	0	10
N. b. E.	52	0	52	0	—	0	0
North.	52	0	52	5	—	0	5
N. b. W.	52	20	52	0	+	0	20
N. W. b. N.	53	20	51	40	+	1	40
N. W.	53	0	51	30	+	1	30
N. W. b. W.	52	40	51	30	+	1	10
W. N. W.	52	30	51	20	+	1	10

Direction of Ship's Head.	Bearing of Shore Station from Ship.		Bearing of Ship from Shore Station.		Difference of Bearings, or Local attraction.		
FEBRUARY 21st, 1825.							
West.	N.53°	10′E.	S.51°	20′W.	+	1°	50′
W. b. S.			51	45			
W. S. W.	53	40	51	50	+	1	50
S. W. b. W.			52	0			
S. W.	54	0	52	20	+	1	40
S. S. W.	54	10	52	40	+	1	30
S. b. W.	54	20	53	0	+	1	20
South.	54	5	53	0	+	1	5
S. b. E.	53	20	53	25	—	0	5
S. S. E.	53	50	53	20	+	0	30
S. E. b. S.	53	0	53	20	—	0	20
S. E.	53	0	53	20	—	0	20
S. E. b. E.	52	40	53	15	—	0	35
E. S. E.	52	45	53	15	—	0	30
E. b. S.	52	40	53	10	—	0	30
East.	52	30	53	10	—	0	40

By inspecting the above Table, it will be seen that the local attraction of this ship was very inconsiderable; it did not even come within the limits of the attractions obtained by Mr. Barlow for his plates. This may be accounted for from the simple fact, that when a compass is placed above the plane of no attraction of a ball of iron, the north end of the needle is drawn towards it, and, when placed below the plane, its south end is drawn towards it. By applying this principle to our experiment, we infer that, whilst the iron below the compass attracted the north end of the needle towards the east or west, the iron mast above the compass similarly affected the south end. Had the deviation in the fourth column been zero, the effect of all the iron on the needle would have been reducible to the case of two opposite forces, equal in their effects, acting at the extremities of the equal arms of a lever, which therefore remains at rest, and is free to obey the impulse of any other force applied to it.

By a reference to the Table, it will be also seen that, with the ship's head towards the east, the north end of the needle was drawn to the east; with her head towards the west, the north end was drawn to the west. Take, for example, when the ship was E. b. N.: the bearing of the ship from the shore station was S. 52° 20′ W.; the bearing of the shore station from the ship was N. 51° 10′ E.; so that the north end of the needle was drawn 1° 10′ eastward of the magnetic meridian. Again, when the ship's head was W. the bearing of the ship from the shore was S. 51° 20′ W.; the reverse bearing was N. 53° 10′ E., proving that the needle was drawn 1° 50′ west. If we examine the other bearings, it will be found that they all follow the same general law as the two examples selected for illustration, from which the following conclusion may be deduced: *that the guns &c. had greater effect on the needle than the mast and bowsprit; so that the local attractions in the fourth column are not to be attributed to the latter, but to the former.* To be more explicit, we will first suppose the ship, independent of the mast and bowsprit, with her fore and aft axis, due north and south (magnetic); in this case, if the iron be equally distributed on each side, its mean resultant will act in the same vertical plane as the terrestrial magnetism; it will not, therefore, have any

tendency to produce a deviation in the needle; but if the ship's head be brought to every point of the compass, passing from the north, through the east, to the south, in the first semicircle the deviation will be eastern; in the second, western;—that is to say, the iron below the compass attracts the north end of the needle eastward with the ship's head east, and westward with the ship's head west, which has been shown to be the case in the present instance. But if the influence of the mast and bowsprit had exceeded that of the iron below the compass, the effect would have been just the reverse; for, with the ship's head towards the east, the south end would have been drawn eastward; with her head towards the west, the south end would have been drawn westward.

As this ship had only a main-mast and bowsprit of iron, the common centre of attraction of all the iron was below the compass, the north end of the needle being drawn forward in every position of the ship. Probably, had the Phaeton been fitted with an iron foremast, the centre of attraction would have been above the compass, and there would have been a tendency still farther to diminish the effect of the guns, &c.; the local attraction might therefore have been reduced to zero, or the combined effects of both masts and bowsprit would have perhaps caused a deviation in the opposite direction; [1] so that, to have produced a magnetic equilibrium, it would have been necessary to have placed a plate before, instead of abaft the compass, as is usually done. This liability of iron masts to produce a deviation in an opposite direction to that which generally takes place in ships, or to draw the *south* end of the needle forward, might lead, without an acquaintance with their effect in this respect, to considerable errors; for there can be no doubt but that the local attraction in vessels has been sometimes accounted for, as it were, unconsciously, by seamen imagining the effect to be produced by currents, &c., which, in reality, proceeds from totally different causes. If, therefore, an allowance be still made for an error which may not exist, or which, if it do exist, may unfortunately be in a reverse direction to what was supposed, the most serious

[1] This was found to be the case in an experiment made by Mr. Barlow on a small model fitted with iron fore and main masts, and bowsprit.

consequences may follow, which are best appreciated by the mariner who is unable, from foggy weather, to take observations for calculating his situation, and is at the same time apprehensive of being near a lee shore.

Although, in the situation chosen by the officers of the Phaeton for the compass, very little deviation was found, we should be misled by supposing there is no local attraction in other parts of the ship, or that azimuth and other observations may be taken indiscriminately forward, aft, or on either side; the only inference to be drawn is, that, with the present quantity and disposition of the iron on board, the compass, *cæteris paribus*, may be confidently used in its original place.

As the needle is brought nearer the magnetic poles of the earth, the iron on shipboard, if it does not *absolutely* acquire more magnetism, does *relatively*, from the diminished action of the earth in giving horizontal directive force to the needle. It may be from hence inferred, that notwithstanding the local attraction, as in the present instance, may be so inconsiderable that it may not be thought necessary to fix one of Barlow's plates to correct it, yet, if the ship is to proceed to high latitudes, either northern or southern, some remedy ought to be applied to counteract the increasing relative influence of the iron.

We may form a better idea of the development of the magnetic fluids in vertical and inclined iron, by considering an experiment given by Biot in his "*Traité de Physique;*" take a small bar of soft iron, unmagnetic, and place it in, or nearly in, the direction of the dip; it will instantly acquire magnetic properties: its upper end, in our latitude, being a south pole; its lower end a north pole: reverse the end, inclining it at the same angle to the horizon, and the poles will be immediately changed. If, instead of soft iron, hard iron or steel be employed, the magnetism will not be so soon developed, but it will be more permanent; and the more nearly the direction of the bar corresponds with the dip, the more powerful will it become, and the sooner will it be magnetized. After it has remained in the above position a certain time, it receives as much virtue as the earth is capable of communicating to it. From similar

principles, we may account for the polarity of the mast when taken out of the ship, which was ascertained by applying a delicate pocket compass to each end, the upper part proving a south pole, and the lower a north pole; it is from hence evident, that the experiment for ascertaining the local attraction should not be made, till the fact of the mast having obtained its permanent polarity is fully established. It was desirable to have formed a correct estimate of the power of the mast, by first removing the compass to such a distance from it, that no visible effect was produced; then gradually placing it closer, and at certain distances, observing the deviations of the needle from the magnetic meridian; but on account of its proximity to immense masses of iron ballast, the experiment would have been unattended with satisfactory results.

The magnetic influence of iron on the needle may be greatly diversified by its chemical combination with carbon, tin, &c. as also by torsion, hammering, and the connexion or tenuity existing between its particles: thus, cast iron, of which the ballast is composed, has not so great an effect as wrought iron. We therefore see that the action on the needle must arise from circumstances which are exceedingly complicated in their nature, as the effect is produced, not only by simple unmagnetised iron, but by artificial magnets differing in their intensity according to the various quality of the iron, and their almost infinite differences of inclination to the horizon.

These considerations concur in establishing the importance of ascertaining the local attraction of the iron on board ships, and the advantage of applying the science of magnetism to the correction of errors, which might otherwise, in some instances, be attended with considerable danger.

Art. XV.—*Recommendation of shifting Mast-Partners.*

To the Editor of Papers on Naval Architecture.

Sir,—I believe it to be a fact very generally acknowledged, that we are frequently unable to obtain the best qualities of the sailing, working, &c. of our ships, on account of the masts

being improperly placed, both as it respects their rake and their position lengthways of the ship.

The experience derived from the qualities of ships which have been tried, appears to be insufficient to decide on the position of the masts of another ship to be built, unless there is a strict coincidence in all the circumstances connected with the design. This, however, is the method at present adopted for determining the position of masts, which is necessarily uncertain, as any deviation in the form of the new ship from the ship that was referred to in the comparison, would require a corresponding alteration. The *principles* of this part of the science of naval architecture are well known; but the theory is not yet advanced so far as to be able to determine, with correctness, the degree of alteration in the position of the masts, corresponding to any variation of form of body.

Till this science be so far advanced as to determine, with certainty, the position of the masts of a ship previously to its being launched, I take the liberty of recommending a plan by which, in making certain arrangements in the vicinity of the mast-partners at the different decks, during the progress of building the ship, the expense and trouble of shifting a mast, at any subsequent period, may be considerably lessened.

In the first place, it will be necessary that the beams immediately before and abaft the masts should have greater spread than is usually given to them, but not exceeding, in any instance, eighteen inches more than at present, which is generally sufficient for any alteration required; for much more than this would doubtless be attended with disadvantage, by weakening that part of the ship where perhaps the greatest strength is required. Now, let there be brought on each side of the mast, at a proper distance from the middle line, a very strong carling with a four-inch rabbet taken out of its upper and inner edge. These carlings must be sufficiently opened to allow a strong frame, which I will call a *frame of shifting mast-partners*, to be moved forward and aft between them. This frame may be made, in all respects, the same as the mast-partners now in use, except that it will project perhaps a little higher above the deck, so that it may conveniently slide in the rabbet before alluded to, which is taken out of the carlings.

Before and abaft this frame the space to the beams must be filled up with pieces resting in the rabbets of the carlings of nine, six, and three inches wide; so that, in the event of its becoming necessary to shift the frame, one or more of these pieces may be taken out from the one side and put in at the other.

If a frame of this kind were applied at every deck, and the common shifting step made use of, (which this frame of shifting mast-partners very much resembles,) a mast may be shifted a considerable distance forward and aft, more than is in any instance practicable at present, without the necessity of incurring the expense and difficulty of taking the mast out.

Whether this plan be the best that can be adopted or not, I will not undertake to say: I only venture to recommend the propriety, and even the necessity, of *some* plan which would have the same object as the above.

You will evidently see that I have only glanced at the plan I allude to: I shall have much pleasure in giving a more detailed description of it, if, at any time, such would be necessary.

I am, Sir, yours, &c.

O.

ART. XVI.—*On a Ship's sinking deeper when at Anchor in a Tide-way, or under press of Sail, than when at Anchor in still Water.*

THE following very interesting communication was received too late to enter to any great extent into the consideration of the subject to which it refers. It may be sufficient at present to explain the *principle* on which the elucidation of the fact depends. In the next Number of this work a more extensive investigation of it may be given:—

Portsmouth, Dec. 8, 1825.

GENTLEMEN,

Understanding you are about to commence a periodical work relating wholly to nautical subjects, I cannot lose the opportunity of eliciting, through the medium of so good a channel, an elucidation of the fact, that when vessels are at anchor in a strong tide-way, or at sea under press of sail, they sink several inches deeper in the water than when at anchor in still water.

This phenomenon I am at a loss to account for, and hope that some of your scientific readers will satisfactorily explain it in your next Number. I am, Gentlemen,

NAUTILUS.

To Messrs. Morgan and Creuze.

M. de Bernoulli [1] showed by experiment, before the Academy of Petersburg, that when water moves with any velocity in a canal, the pressure it exerts on the sides of the canal is less than it exerts when at rest, according to its velocity. M. l'Abbé Bossut obtained similar results. M. Romme made experiments to determine the pressure of water under the same circumstances, and ascertained with great accuracy the decrease of pressure exerted by the water in relation to its velocity.

When water is at rest, every particle presses equally in all directions in proportion to its depth below its surface, and therefore exerts on any body floating on it, a pressure in the same proportion. The total number of particles of the water in contact with the body, supports its weight by their vertical pressure, as it supported previously the volume of water displaced by the body, the weight of which is equal to the weight of the body, as the equilibrium of pressure remains the same. But when any particle is impressed with motion, and passes along the surface of the body, it no longer presses equally in all directions, having a greater tendency to escape in the direction of its motion than in any other; its vertical pressure is therefore less on the surface of the body than when at rest. The total pressure of the particles of water in contact with the body being less than before, and having been, when at rest, only exactly equivalent to sustain the body, the body sinks deeper, till their vertical pressure becomes equal to the weight of the body.

It is shown, that the pressure of a particle of water in motion is proportional to its depth below the surface of the water, minus the depth due to the velocity estimated in the direction of its motion.

These remarks, it is considered, may elucidate the principle on which the fact depends. M.

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[1] L' Art de la Marine, par M. Romme.

PAPERS

ON

NAVAL ARCHITECTURE,

&c.

ART. XVII.—*Remarks on 'A Complete Theory of the Construction and Properties of Vessels,' by L. Euler; translated into English by Colonel Watson.*

THE science of Naval Architecture is a subject which peculiarly demands a very extensive view to be taken of it. To consider it as a mere question between the theorist and the practical man, is the most injurious method of its investigation that can be adopted for its advancement; by contracting the subject within limits, which prevent a just consideration of it. It tends to lower the value of the labours of both, as the one or the other may be unduly appreciated, in the different opinions of their respective advocates. The enlightened philosopher does not estimate the discoveries of the one, at the expense of those of the other; but rather endeavours to collect the whole, and render them tributary to the general improvement of the subject.

Few departments of philosophy are totally unconnected with naval science. The mathematician determines many of the qualities of vessels, by the regulation, according to established laws, of the properties of floating bodies, and disposes their different parts in dependence on each other, and in proportion to their strain, by which alone a machine can be properly constructed; the mechanic renders the design of the engineer effectual, by the soundness of the workmanship; the chemist ascertains many of the properties of the materials, of which the fabric is composed, and directs or forbids their contact in accordance to the laws of affinity, by which their deterioration

by decomposition may be retarded; and the astronomer gives rules for the guidance of the well-constructed vessel with safety to its destination.

Every elucidation of the laws of nature necessarily tends to improvement, by enabling a nearer approach to certainty to be made, in the attempt to give excellency to any design.

By opposing what is commonly called experience and facts, to theory, truth is very frequently much obscured. It was a remark often made by Dr. Cullen, that "There are more false facts current in the world, than false theories." The great difficulty of making correct experiments, and of observing facts in connexion with all the circumstances which affect them, renders it necessary to examine them with the strictest attention, previously to the admission of their truth. To omit any circumstance, which influenced the result, might lead to very erroneous conclusions, by allowing a law to be established on insufficient data, and the effect to be attributed to a cause, at least inadequate. The more complicated a subject may be, the more necessary is science to the proper examination of the facts. The more certain method of arriving at a correct theory, is by the application of science to the results of experience and observation; but it is at the same time probable, that more false theories have been founded on a superficial and unscientific observation of facts, than have been deduced from uncertain hypotheses.

The application of science to the results of experience is not only necessary to render them extensively useful in practice, and ensures greater correctness to the subject under consideration, but in numerous instances reduces the number of necessary experiments within practicable limits. It is in this manner that experiments and observations on ships made by naval officers, perfectly within limits consistent with general service, would be amply sufficient, by the application of science, for the improvement of naval architecture. Mere experiment can never lead to such beneficial results. Suppose that a ship, when fitted and stored for sea-service, is found on trial to possess some quality in an eminent degree:—suppose, for instance, that the stability is found to be in a proper proportion, and well regulated; so that she is sufficiently stiff under sail, and at different angles of inclination its increase is uniform.

To become fully acquainted with this fact, so as to render the knowledge of it useful to future designs, all the circumstances connected in any way with the stability must be correctly observed. To ascertain entirely by experiment all the elements of the design which influence this property, would require a most extensive series of experiments; and to ascertain by experiment alone, not only the principles which affect this property, but the proportional effect which each produces, would be still more difficult, from the vast number of experiments which would be required,—so vast, indeed, as to be scarcely practicable; but to obtain, by experiment alone, the correct measures of all the effects produced by different variations of the elements, for *all* the properties of a ship, would so far surpass all conception of experimenting on ships, that if this were the only means of improvement in naval architecture, great improvement must be hopeless. The relative dimensions of the well-constructed ship, its form, stowage, masting, and calculated elements should be correctly taken; and experiments should be made by alterations in the variable elements under as many circumstances as may be conveniently practicable, and their results carefully observed. In this manner the proportional effects of several of the elements may be ascertained; and by calculations made on them, rules applicable to future practice may be obtained, which, in connexion with similar experiments and calculations on other ships, will regulate with certainty this property in future designs.

It has been frequently observed, that the best vessels of certain descriptions have been built by what is usually termed by practical men, "the eye," without any reference to science. Fast-sailing cutters, for instance, possessing every requisite quality, are frequently built without any connexion with mathematical science. This is a class of vessels, for the construction of which many private English builders are particularly distinguished, and which is managed by English sailors with extraordinary skill. There are, however, peculiarities in this vessel, both in its design and management, which require an intimate acquaintance with them, to excel in. Its being a favourite description of vessels for many purposes, has rendered a particular attention to it an object of profitable trade, which has

neeessarily tended to produce excellency in its construction. A large proportion of this class of vessels answers well; but the great excellency of a few, is established only by the inferiority of others; and many are found to answer but very indifferently, and some built after considerable experience are decidedly bad. But it is asked, as this difference of character exists in all classes of vessels, and very many cutters are unquestionably excellent, which have been built without mathematical science, what is the use of science to this class of vessels; and if not to this class, why necessary to any other?

In the first place, mathematical science, in connexion with great practical experience, would not deprive the constructor of the advantages of his experience, which would at least be as beneficial, as it could have been in the case of the most complete ignorance of the established principles of science. But it would not leave him merely as he would have been without it: it would enable him to understand the principles of the system on which he constructs his vessels, so that he may increase or diminish many of their qualities with certainty in his future constructions. Suppose that a mere practical builder, whose knowledge is founded entirely on experience, and who has arrived at great eminence in the construction of a particular class of vessels, be required to build a vessel of a description totally different, on what principles can he form his design?—Experience in this class of vessels he is supposed not to have. Probably on vague notions and incorrect analogies. Science in this case would have directed him by established principles, at least to a certainty of obtaining the essential qualities of the vessel; and in proportion to his acquaintance with the science of naval architecture, to the probability of excellency in all its properties.

But the writer of these remarks, instead of opposing experience to science, would rather consider this experimental knowledge, as far as it is sound and just, as a degree of scientific knowledge, sufficient perhaps for a very limited practice of building a particular class of vessels, but totally inadequate to the general design of ships. A cutter builder who, after many years' experience, is able to build cutters which possess very eminent qualities, might probably, had he been early in life

acquainted with the established principles of science, have been a celebrated naval architect. The observations which he may have made on the forms of the vessels he has seen, with an acquaintance with their properties, through his ingenuity and judgment, may have at length formed a mass of evidence, concurring to establish the necessary connexion between a certain form and some particular property, which becomes a principle of his future practice of construction. This is, as far as it extends, agreeable to the principles of the inductive science, and is defective only from its very limited character, wanting more numerous data, and laws deduced correctly from them by mathematical reasoning, which may be generally applicable to practice.

It must not however be forgotten, that much which is received in the world as certain, in consequence of being the results of experience, is little or nothing more than habits derived from a continued repetition of errors, prejudices, and a reluctance to acknowledge the advantages of science.[1] Such an experience must necessarily be dangerous, as being directly opposed to the investigation and developement of the laws of nature. Attachment to such a system as this would not only check improvement, but would cause the knowledge of naval architecture, which has arrived at its present state through the numerous labours of the experimentalist, the mathematician, and the philosopher, gradually to sink into total uncertainty and absurdity. It is the same spirit, which by casting the opprobrious epithet of "mere theory" on scientific investigation, has constantly attempted to check the progress of improvements, however soberly and legitimately conducted. Fortunately we live

[1] It is not intended to apply this remark to those, who, in the true "humility of wisdom," have cautiously and gradually arrived at considerable knowledge of naval architecture by long experience and the application of such science, although perhaps very limited, as they possessed, and who by their practice acknowledged the advantage of science, while they may have expressed their belief, perhaps rather too exclusively, in the benefits to be derived from observation and facts,—but entirely to those, who either through a perversion of reason and common sense, or from a dislike to acknowledge in others what they want in themselves, uniformly oppose the application of mathematical science to the improvement of this difficult and extensive subject.

in a country and at a period, in which the influence of government is exerted, by an enlightened and extensive view of the resources of nature and of art, in rendering scientific labours tributary to general improvement.

On the other hand, hypothetical theories, brought forward by mere speculators and pretenders to science, although in some instances containing a few good remarks, by their general absurdity have been properly treated with contempt. No theory, however, which has been brought forward by men of real science, has been unattended with some advantage to the subject, either by elucidating the relations between different combinations of established principles, or at least, by pointing out the methods of investigation to those, who may be better acquainted with the facts and experience of the subject.

Among those who have applied mathematical analysis to naval architecture, with the least acquaintance with the experience and facts connected with it, was Euler, who, in his day, was [1] "unquestionably the first analyst in Europe for his resource and address." He frequently disregarded the correctness of his physical assumptions, and contented himself with the elegance of his investigations, which in some cases gave results totally inconsistent with the effects of established principles. With the philosophy of naval architecture he was but very little acquainted, although he wrote much on the subject.

Although many parts of naval architecture require, as has been said, very extensive experiments as the foundation of mathematical reasoning, there are, however, other parts of the subject, which may be treated with great advantage, on the general principles of mechanics, which are as strictly applicable to ships as to other bodies. In these parts of the subject, his investigations are very valuable, being true in their principles, and generally pursued by him, to the attainment of clear and intelligible results.

He presented several memoirs on some of the branches of this science to the Academy of Sciences of Paris, and published

[1] See Professor Robison's remarks on Euler, in the article on the 'strength of materials,' in the Encyclopædia Britannica.

two treatises on naval architecture, one in Latin, entitled 'Scientia navalis, seu tractatus de construendis ac dirigendis navibus,' in 1753, and the other in French, entitled 'Theorie complette de la Construction et de la Manœuvre des Vaisseaux,' in 1773. The latter work was published in Petersburgh, and was translated into English by Colonel Watson.

This work is divided into three books: 1. The Consideration of Vessels in Equilibrium and at Rest; 2. On the Resistance which Vessels experience in their Courses, and on the Action of the Rudder; and, 3. On the Masts, and on the Management of Vessels at Sea; with a Supplement on the Action of Oars,—which was sent by Euler to Colonel Watson in manuscript, while he was translating the former part of the work into English, who made some additions to it previously to its publication.

He commences his consideration of the equilibrium of a vessel by establishing these two principles: "1st, That the immersed part must be equal in volume to a mass of water, whose weight would be equal to that of the vessel; and, 2dly, That the centre of gravity of the vessel, and the centre of gravity of the displaced volume, fall in the same vertical line, which is the vertical axe of the vessel."

He shows that a vessel is liable to arching longitudinally, technically called "hogging," in consequence of the inequality of the pressure of the weights downwards in different transverse sections of the vessel, and the pressure of the water upwards in the corresponding sections of the displacement. It is impossible to render these opposite forces equal in the different parts of a vessel, in consequence of many of the great weights in vessels being necessarily placed in parts where the buoyancy is unequal to them, particularly at the extremities, which, from their fineness of form, cannot exert a buoyancy equivalent to the pressure downwards of those weights, which must always be placed at these parts. He does not, however, enter into the investigation of this subject, contenting himself with explaining the principle.[1]

[1] Sir R. Seppings, F.R.S., one of the Surveyors of His Majesty's Navy, has lately introduced a new system of diagonal framing in the holds of ships, and trusses between the ports, with other improvements, to prevent this breaking, which greatly weakens the fabric.

In treating on the stability of a vessel, which is the force which the vertical pressure of the water exerts, when the vessel is inclined, to restore it to its upright position, he considers the efforts of the moments of the weight of the vessel, and of the immersed volumes, in causing the vessel to revolve round its horizontal axis, when there is an equilibrium. His manner of conducting this investigation is very inadequate to give a just and clear knowledge of the subject. By reducing the expressions representing the stability of a vessel, to the moments of the plane of floatation, referred to the longitudinal and transverse axes, the forms of the parts which are immersed and emerged by the inclination, are omitted in the results; and the measure of the stability is estimated as depending only on the length and breadth of the vessel, its weight, the total volume displaced, with the distance between the centre of gravity of the vessel and the centre of gravity of the displacement. By the omission of this necessary element in the consideration of the stability, the investigation is incomplete, and the result erroneous. Although the error of comparing the relative stability of two vessels by this method, would in most cases in practice be small, there are conceivable cases, in which the error would be great; and there are many vessels in use, whose forms are such, that if the stability were measured by this method at great inclinations, the error would be too great to be neglected.

The moments of stability of the plane of floatation are compared, with respect to the longitudinal and transverse axes, and are shown to be, in the same vessel, inversely proportional to the squares of these axes: that is, in a vessel whose length at the plane of floatation is four times its breadth, the moment of stability round the transverse axis is to the moment of stability round the longitudinal axis, as 16 to 1. He deduces from the moments with respect to these two axes, the moments with respect to all intermediate axes: supposing the angle of inclination of the intermediate axis with the longitudinal axis to be represented by i, the moment with respect to the larger axis by A, and the moment with respect to the shorter axis by B, he proves that the moment with respect to the intermediate axis is $= \mathrm{A} . cos . i^2 + \mathrm{B} . sin . i^2$.

Euler observes that "Since we consider here only very small inclinations, and because the security of navigation absolutely requires that vessels be never exposed to inclinations that are too great, it is necessary that the stability be always several times greater than the greatest momentum of the forces to which vessels can ever be exposed. Here is, therefore, a precept of the last importance in the construction of vessels,—that it is always necessary to procure for a vessel such a degree of stability as may be many times greater than the greatest efforts which the vessel can ever be exposed to. Thus, if we should require that the inclination shall never surpass ten degrees, whose sine is about $\frac{1}{6}$, it is necessary that the stability be at least six times greater than the said efforts to which the vessel might be subject."

These remarks are altogether inconsistent with the nature of the stability of vessels;—that the stability of a vessel should be six times greater than the greatest momentum of the inclining forces to which it is exposed, considering the greatest inclination consistent with safety not to exceed ten degrees, because the sine of 10° is about $\frac{1}{6}$ the radius, is an argument which by no means justifies the conclusion. Euler probably considered, that if a certain force was equivalent to the stability at a very small inclination, the *same force* multiplied into the sine of the angle of any greater inclination, must be equal to the stability at this increased inclination. This is by no means true. Supposing that the sine of the angle of inclination might be taken at least as an approximate though incorrect relative measure of the stability at different angles, the stability would then increase as the sine of the angle of the increased inclination; and the stability at a very small angle would therefore be very small compared with the stability at ten degrees. Whenever the form of the volumes immersed and emerged by the inclination is neglected in the measurement of the stability, the sine of the angle of inclination must be always substituted in determining the relative stability at different angles of inclination.

The stability of a vessel should be so regulated, by the elements affecting it, that it should increase uniformly as the inclination increases, and should become so great at an inclina-

tion of about ten degrees, that the greatest inclining force to which vessels are subject may not be able to increase its permanent inclination much beyond this limit. The stability should also continue to increase beyond the angle of inclination to which vessels are liable in the most extreme cases.

The stability of vessels being in the proportion of the fourth power of the simple dimensions, in perfectly similar vessels, "great vessels would in proportion have more stability than the small ones;" and as the inclining forces of the wind "are in proportion to the cube of their dimensions," the large vessels would incline less than the small vessels; which is agreeable to what ought to be the case in practice, as "equal inclinations might become fatal to great vessels, at the same time that small ones would be out of danger."

In the chapter on the rolling and pitching of vessels, although the author fails in establishing his assertion, that the "vibrations of a vessel round any axe whatever to which the inclination has been made, are perfectly like the oscillations of a pendulum," yet he arrives at a conclusion, true in practice, and which admits of a clearer and more just investigation on some of the principles connected with the oscillations of a pendulum: that by removing the weights from the axis of rotation, the rolling and pitching would be deeper, and easier, than when placed nearer to it.

In the second book, Euler founds his theory of the resistance a vessel meets with in its courses, on the supposition that two equal plane surfaces would experience exactly the same effect, if one were moving directly through the water with a given velocity, and the other sustained a column of water, whose height was that due to this velocity. Representing the velocity by c, the area of the plane by f^2, and the height through which a body would fall by gravity in one second by g, the force of the resistance, under this supposition, will be $= \frac{c^2 f^2}{4g}$.

The resistance in oblique courses he determines by the resolution of forces, in a direction contrary to the motion, to be $\frac{c^2\ f^2\ sin.\ \phi^3}{4\ g}$, ϕ being the angle the surface makes with the direction of its motion.

On these principles he investigates the resistance the fore-

part of a vessel meets with, both in its direct and oblique courses; the resistance on the after-part of the vessel he notices as affecting the total resistance, but neglects it in the general expression he gives for the resistance vessels meet with, moving in the water.

This theory will be more particularly considered hereafter, in the course it is intended to pursue, in the examination of the different theories and experiments on the resistance of fluids.

Euler applies this theory to the determination of the relation between the angles of lee-way and the moving force of vessels. His analytical investigations and general reasoning, on this subject, are very valuable and beautiful; if his results are not strictly correct, the investigation of them illustrates many of the true principles which govern them, and they at least approximate sufficiently near to truth to render them useful. Representing the greater axis of a vessel by a, and the shorter axis by b, the angle of the obliquity of the course or the lee-way by ϕ, and the angle of the obliquity of the acting force by ψ, he determines that $tang.\ \phi = \sqrt{\frac{2\,b^3}{a^3}}.\ tang.\ \psi$; from which expression tables are calculated, showing the corresponding angles of lee-way and of the obliquity of the acting force, for vessels of different relative proportions of length and breadth.

Three valuable chapters are given on the action of the rudder in causing a vessel to revolve round its vertical axis. It is shown, that when a vessel sails in a direct course, if the angle which the after-part of the body at the line of floatation makes with the longitudinal axis is 45°, which in very many vessels is not far from the truth, the rudder, to produce the greatest effect, should make an angle of 29° 19′ with this axis; and that at the keel, where the water may be supposed to run in the direction of the longitudinal axis, the angle of the rudder with this axis, to produce the greatest effect, should be 54° 44′. He says, "Hence we may draw a very important conclusion for navigators, that in order to obtain the most speedy and greatest effect from the action of the rudder, it is necessary to give to it an obliquity something less than that of 54° 44′, which has been hitherto prescribed by mathematicians; for if the highest or water section of the body requires an obliquity of 29° 19′,

whilst the lowest section would demand one of 54° 44′, it is necessary, without doubt, to make choice of some mean between these two limits: the mathematical man would give an angle = 42° 1′; but as the rudder has a much greater breadth at bottom than at the level of the water, and besides the effect of the water much greater than at the surface, the mean to be fixed upon ought to be much nearer the greatest limit. From whence it seems that we might establish this rule: that an obliquity of about 48° will in general produce the best effect; or rather, in order to obtain the greatest effect, the helm ought to make an angle of 48° with the axis of the vessel, or at least one of 45°, since the differences which arise near a maximum are almost insensible."

In oblique courses it is shown, that the angle which the rudder will make with the fore and aft axis, to produce the greatest effect, differs from that in a direct course, as the different directions of the water which meet the rudder produce different effects on it, and thereby influence the angle of inclination. When the rudder is turned to leeward, the water runs more freely on it; and taking a case within the most probable limits, he shows that the angle of the rudder at the keel, to produce the greatest effect, would be 49° 35′, instead of 54° 44′, the angle in the direct course of the vessel; and as, at a section higher up, the water will also run more freely on the rudder, and lose less of its velocity, than it did in the direct course, he considers that the angle of the rudder, to produce the greatest effect in an oblique course, would not be above 40°.

When the rudder is turned to windward, the effect of the water on it is greatly reduced, from the direction of the water being less effective, and its not flowing freely on the rudder. "In this situation vessels do not generally answer their helm well, and it frequently becomes necessary to aid the rudder by the use of sails in bringing a vessel to windward."

It is not, however, necessary to correct every deviation in the course of a vessel, by moving the rudder through a great angle. The rudder should be brought to the angle of obliquity to produce the greatest effect on a vessel, only when it requires to be turned suddenly.

The resistance on the after-part of the rudder is entirely neglected in the investigation.

Euler, in his third book, commences his investigation of the masts and sails of vessels, by adopting the same theory for the effect of the force of the wind striking a surface, as for the force of the water, reducing the expression in the proportion of the specific gravity of water to air, which is as 800 : 1; so that the general expression which he gives for the force of the water acting on a surface moving in a contrary direction to its motion, $\frac{c^2 f^2}{4g}$, becomes for the force of the wind acting directly on the same plane, $\frac{c^2 f^2}{800 \cdot 4g}$. When the wind strikes the plane at an angle of obliquity represented by θ, he represents the force of the wind by the expression $\frac{c^2 f^2}{800 \cdot 4g} \cdot sin. \theta^2$.

Euler explains the difference between the apparent direction of the wind in vessels under sail, shown by the vanes and flags, and the true direction of the wind, and investigates a formula, by which the true direction of the wind may be found from the apparent direction; which is commonly done at sea by putting a vessel on opposite tacks close-hauled, and taking half the angle formed by the two courses. Taking any line to represent the direction and velocity of the vessel in one second, this line in the opposite direction may represent the resistance of the air, supposing the air calm and the vessel moved by another power; taking another line to represent the direction and velocity of the apparent motion of the wind. By completing the triangle, the third side shows the direction and velocity of the true wind. The force of the apparent wind may be estimated at sea by an instrument formed for this purpose: M. Bouguer and others have invented instruments by which it may be very correctly measured. Representing the velocity of the apparent wind by u, the velocity of the sail by v, the angle which the apparent wind makes with the direction of the velocity of the sail by η, and the angle which the direction of the true wind makes with the direction of the velocity of the sail by ζ, he determines that $tang. \zeta = -\frac{u \cdot sin. \eta}{v - u \cdot cos. \eta}$.

Euler considers the point which is called by several writers on naval architecture, the *centre velique*, which is the point at which the resultants of the direct and vertical forces of the water on the fore and after parts of the vessel's body intersect, as the same with the centre of effort of the sails. Considering the vessel as sailing before the wind, these points would be nearly coincident, but not necessarily so; as it is only the moment of the wind on the sails and the moment of the resistance of the water on the ship's body which are equal; but in oblique courses the centre of gravity of the sails, or their centre of effort, is necessarily much higher than the resultant of the force of the water on the ship's sides.

He concludes his treatise by a very elegant application of his principles to the determination of the relative angles of obliquity of the direction of the wind, the direction of the sails, the direction of lee-way, and the vessel's velocity. Taking a for the vessel's length, b for its breadth, ψ for the angle of obliquity of the acting force, or of the wind, and ϕ for the angle of lee-way, e for the vessel's draught of water, and v for the velocity of the vessel, he expresses the vessel's resistance by $\frac{v^2}{4g} \cdot \frac{3}{4} ae \cdot \frac{sin. \phi^2}{sin. \psi}$. The angles of obliquity of incidence of the wind are then connected with these investigations. He forms numerous tables, which give the numerical values of the results of these investigations, for vessels of different relative dimensions, by increasing the angle of obliquity of one of these quantities, which is supposed to be given, by small increments, in relation to which the other quantities are determined. The tables include many cases which exceed the limits of practice, both with respect to the relative dimensions of vessels and the obliquity of the sails, which however are necessary for the full developement of the principles. The value of these tables can be best estimated by those navigators who consult them most, and compare them with the results of their experience. Although from being unacquainted with much of the philosophy of naval architecture, Euler may not have arrived at results strictly correct in all cases, especially in those parts of the subject dependent on his theory of the resistance of fluids, yet the relation between the different angles of the obliquity of the wind, sails,

and lee-way, is clearly explained; and if the true results of experimental philosophy be substituted for what in many instances in his treatise is hypothetical, the advantage of his mathematical investigations may be rendered still greater, by the results in his tables being strictly correct and agreeable to practice.

The Supplement to this work gives a clear elucidation of the action of oars in propelling a vessel through the water. The effect of the power of different numbers of rowers, in giving the vessel different velocities, is investigated, with the proportion between the parts of the oar within and without the vessel. A table is given, showing the results of these investigations, in which the increase of velocity is shown to bear a small proportion to the increase of the number of rowers: it appears by this table, that if the power of one rower can communicate a motion of a little more than six miles in an hour to a boat, it would require the power of five rowers to give it about double the velocity. This is independent of the increased resistance in consequence of the increase of the number of the rowers in the boat.

This work may on the whole be considered as showing fairly what advantage the application of mathematical science may be to naval architecture, when as little connected with experimental knowledge as in any work on the subject; but had Euler been as well acquainted with the philosophy of this subject as with mathematical analysis, it is difficult to estimate the extent to which naval architecture might have been benefited by his labours.

M.

Art. XVIII.—*The Parabolic System of constructing Ships, invented by Admiral F. H. Chapman; communicated by* Lieutenant A. G. Carlsund, *of the Swedish Royal Naval Engineers.*

The system which is at present used by the Swedish Engineers, in the construction of ships, was the result of the labours of the latter years of Chapman's life; it is called

the parabolic method, and is explained in a work entitled, *Försök till en Theoretisk Afhandling att gifva åt Linie Shepp deras rätta Storlek och Form Likaledes för Fregatter och mindre Bevärade Fartyg. af F. H. af Chapman. Carlskrona,* 1806.

The following paper is an outline of this description, with some few alterations, which the writer considers may perhaps render the calculations more simple.

By making calculations on a number of ships which have been found to possess good properties, and subjecting the results to scientific investigation, we are enabled to state what displacement and what dimensions a well-constructed ship should have; we can also determine where the centre of gravity, in respect to length, should be placed; but we cannot by the usual methods of construction, without very great labour, determine the area of the midship section, its distance before the middle of the length, and the areas or forms of the other sections, so as to ensure having this requisite displacement, nor that it shall be so distributed that the centre of gravity shall be in the required situation. It was to supply these deficiencies that Chapman invented the method which is the subject of this paper.

As the above-mentioned elements depend upon the areas and situations of the several transverse sections, Chapman endeavoured to discover whether or not these areas, in well-constructed ships, followed any law; and if so, to find the law. For this purpose he calculated the areas of the sections of several ships; and in order to make the numbers more convenient, he divided the areas by the breadth of the midship section; then setting off from the water-line, at the respective stations on the drawing, distances equal to the quotients, he traced a curve representing the areas, which he called the curve of sections. He then endeavoured to find the equation to the curve, or rather that of another curve which would coincide with this for the greatest length; and he found that if the power and parameter of a parabola were so determined as to allow that curve to pass through three given points of the curve of sections, the two curves would nearly coincide. In the fore body the three points were taken, one forward, one at the midship section, and one midway between. In the after

body the points were similarly situated. In some ships the exponent to the curve was higher in the after body than in the fore body, in some it was the same for both; it was also found that there were ships in which the curve of sections almost exactly agreed with the parabola, and these ships invariably bore excellent characters. Chapman consequently concluded, that if the areas of the several sections of a ship were made to follow the law of the abscissas of a parabola, a vessel possessing good sailing qualities might be formed, and the process of construction much simplified.

This account shows that this method is deduced from experience, by theoretical investigation; it is applicable to all sorts of constructions, as it only requires that the relative areas of the sections shall decrease from the midship section towards the extremities, in a certain relation which can be varied to infinity; it is therefore equally useful in constructing the sharpest man-of-war, as the fullest merchant-man.

It may perhaps be objected, that the alterations which have taken place in the forms of the bottoms of ships, since the introduction of this method by Chapman, in 1806, would probably give different results; it is therefore desirable that this should be ascertained by a series of calculations on the bodies of some of the most modern ships which have been found to answer.

Suppose a ship is found to answer well at some given water-line, AC (Fig. 8). Let the areas of the transverse vertical sections be divided by some constant quantity, as, for instance, the breadth, and suppose the distances $a\,b$, $c\,d$, &c. equal to the quotients, to be set off on the respective sections, from the water-line; then a curve drawn through the points b, d, &c. will be the curve of sections. It will be found to be convex to the water-line at the extremities.

The order of the parabola which coincides for the greatest distance with this line, may easily be found.

Let the general equation to the parabola be expressed by $y^n = a\,x$; then it is always possible to determine n and a, so that the parabola shall pass through two points besides the vertex; any two points between b and C may be taken, but it is evident

that the farther apart the three points are taken, the longer will the parabola coincide with the line of sections; of course neither point may be in the convex part of the line of sections. It will be found that the point g, at the foremost frame, and h in the middle between g and b, are the points which should be taken.

Draw a tangent to the curve at the point b, which will be of course parallel to the water-line; then $m\,h$ and $n\,g$ are abscissas; $b\,m$ and $b\,n$ ordinates to a parabola passing through b, h, and g; put $m\,h = x'$ $n\,g = x''$, $b\,m = y'$, and $b\,n = y''$; then substituting these values in the equation to the parabola, we have

$$y'^n = a\,x,' \text{ and } y''^n = a\,x''$$

$$\text{or } n\,.\,log.\,y' = log.\,a + log.\,x' \text{ and}$$

$$n\,log.\,y'' = log.\,a + log.\,x''$$

$$\text{hence } n = \frac{log.\,x' - log.\,x''}{log.\,y' - log.\,y''}$$

$$a = \frac{y'^n}{x'}$$

$$\text{and } log.\,a = \frac{log.\,x'\,.\,log.\,y'' - log.\,x''\,.\,log.\,y'}{log.\,y' - log.\,y''}$$

We have now the values of n and a, and by calculating several other abscissas we can trace the parabolic curve. The same operations, applied to the after body, will give the exponent and parameter of the parabola, which is the most similar to the curve of sections in that body.

It generally happens that the exponents are nearly the same in both bodies, if the place of the midship section be determined in the manner shown in the sequel.

It will be found that the parabola and the line of sections very nearly coincide; the former being sometimes a little within the latter between g and h, and without at the fore side of h; and sometimes, but much more seldom, the contrary. The parabola always cuts the water-line at a short distance from the rabbets, this distance being rather greater forward than abaft.

Several American ships of war have been submitted to this method of investigation, which was found to answer very well with their bodies; indeed there can be no great deviation, as the

parabola varies according to its exponent and parameter; if the ship is full, a large exponent adapts it to that shape; and if the ship is lean, a small one. If the body has a long straight of breadth, and sharpens quickly at the extremities, by deducting a part in midships from the comparison, the system may still be applied; or if, as is the case generally with English merchant-ships, there is a very great draught of water in proportion to the breadth, by deducting a part from the water-line downwards, this method may be applied to the remainder.

From this reasoning it appears that ships may be constructed to coincide exactly with the parabolic line, without deviating from the forms which experience has proved to be the most conducive to giving ships good qualities. Chapman stated that this system would most probably be superior to the old one, and the result has confirmed his statement; for ships of the line, frigates, and merchantmen, have been constructed after it, all of which have been very fine vessels.

From the manner in which the curve of sections is formed, it follows that its area, multiplied by the breadth, is equal to the displacement, and that the centre of gravity of the area is in the same transverse section as the centre of gravity of the body; but the area of this curve, supposing it to be a parabola of a certain power, is a known part of the rectangle formed by the greatest ordinate and the abscissa; hence by making the areas of the sections decrease in the ratio of the abscissas in the parabola, we obtain certain equations between the quantities. To find these equations, suppose the parabolic line, now also representing the line of sections, to be ACB, (Fig. 9,) cutting the water-line at some distance from both rabbets; let C be the place of the midship section, and DC the greatest abscissa. Put $AB = l$ and $DC = d$, let the exponent of the parabola before and abaft $= n$, and the displacement $= D$; then the area of the parabolic line $BDACB = \frac{n}{n+1} \cdot l \cdot d$, and the displacement $= \frac{n}{n+1} l \cdot d \cdot B$ (B representing the breadth); but $dB =$ area of the midship section: hence

$$\frac{n}{n+1} \cdot l \cdot (\textit{area of midship section}) = D \quad - \; - \; - \quad (1.)$$

Let E be the middle point of the water-line AB, which we may call the construction water-line, F the place of the centre of gravity in point of length; let ED, the distance the midship section is before the middle of the water line, $= k$, and EF, the distance the centre of gravity is before the middle, $= a$; we will now determine the place of the midship section in reference to the situation of the centre of gravity F.

As BCD represents the displacement of the fore body, and CDA that of the after body, the moments of these two parts will give the common moment.

The centre of gravity of the parabolic area is at a distance from the abscissa DC

$$= \frac{n+1}{2n+4} \times \text{ the ordinate DB};$$

and for the parabolic area DCA it

$$= \frac{n+1}{2n+4} \text{ DA}.$$

The moment of DCB from the point E

$$= \left(k + \frac{n+1}{2n+4} \cdot \text{DB}\right) \cdot \text{DCB},$$

and the moment of DCA from the same point

$$= \left(\frac{n+1}{2n+4} \cdot \text{DA} - k\right) \text{DCA}.$$

But the areas of DCB and DCA are proportional to DB and DA, and the sum of the above moments = EF. BCA, or $a \cdot l$ l representing the area: hence

$$a\,l = \left(k + \frac{n+1}{2n+4}\text{DB}\right)\text{DB} - \left(\frac{n+1}{2n+4} \cdot \text{DA} - k\right) \text{DA}.$$

$$= -\frac{n+1}{2n+4} (\text{DA}^2 - \text{DB}^2) + k\,(\text{DB} + \text{DA})$$

$$= (\text{DA} + \text{DB}) \cdot \left(-\frac{n+1}{2n+4} \cdot (\text{DA} - \text{DB}) + k\right)$$

but $\text{DA} - \text{DB} = 2\,k$, and $\text{DA} + \text{DB} = l$; hence

$$a\,l = l\,k \cdot \left(1 - \frac{n+1}{n+2}\right)$$

$$a = k \cdot \frac{1}{n+2}$$

or $k = a \cdot (n+2)$ - - - - - - - - - - - - (2).

That is, if the midship section DC is placed at such a distance k from the middle point of the construction water-line, the centre of gravity will be in the point F assigned to it.

These two equations, (1) and (2), form the principal foundation of the parabolic method of construction. In the first equation, any quantity may be known by assigning values to the others; and in the second, by fixing a value for the distance of the centre of gravity before the middle, the place of the midship section will be known; then having by the first equation found the exponent of the parabola, any abscissa, GH or KL, may be calculated. Suppose, for instance, GH to be required: then in the first assigned equation $y^n = a\,x$, n is known; also y and x are known for a certain point B, through which the parabola passes; the value of y for this point is DB, and of x is DC. This gives $a = \frac{\text{DB}^n}{\text{DC}}$

$$= (\text{by putting DB} = f)\frac{f_n}{d} \quad - \quad - \quad - \quad - \quad (3).$$

Now GH is easily determined in the above equation, by assigning a value to CG, if CG or any other ordinate is expressed by y', the corresponding abscissa GH $= x'$ is determined by the equation

$$x' = \frac{y'^n}{a} \quad - \quad - \quad - \quad - \quad - \quad (4).$$

This equation is sufficient for calculating the areas of all the sections for the fore body; and for those of the after body, we have the equation (3), in which, by substituting f for DA, we get the value of the parameter, a', of the parabola of the after body, and substituting this value for a in equation (4), and giving to y' any value CK, a corresponding abscissa LK is obtained; and in the same manner as many may be found as may be thought proper. It is evident that GH and LK must be subtracted from the largest ordinate DC, to give G′H and K′L, which represent the areas of the corresponding sections.

This method of first calculating the abscissas and then subtracting them, may appear indirect, as the true lines G′H and K′L could have been obtained at once by transforming the equation of the parabolic line to another, beginning at the point D; but it would then have lost its simplicity, and the

calculations would not have been easier than by this method. One thing may however be done, which is, to substitute the area of the midship section, instead of its quotient, by the breadth; by which the whole areas of the other sections will be obtained, instead of the lines which represent them.

The principles of the parabolic method being now explained, it will be easily seen how very useful its application is to the comparison of all ships, whether they were constructed with or without reference to it.

By referring to equation (1), we find that the displacement, area of midship section, and the construction water-line, being known, the exponent of a parabola that coincides most nearly with the line of sections is easily found, and we shall have (putting M for the midship section) the value of

$$n = \frac{D}{l\,M - D} \quad - - - - - - - - \quad (a).$$

This value of n shows the degree of fulness of the ship; and as it refers us to a geometrical line, it gives us at the same time a geometrical and arithmetical expression for the relative fulness, and is in consequence preferable to the method which is sometimes used,—that of giving the proportion between the displacement and the circumscribing solid, which only gives an arithmetical expression.

This parabolic method may also be applied to show the relative fulness of the midship section, of any of the water-lines, of the displacement with respect to the water-line, and of several other elements.

Let ABC (Fig. 10) represent a midship section, and let EF be a tangent to the curve at the point of contrary flexure C; the small area ECD, not being of any importance, may be neglected. If the midship section is at all similar to those usually given to ships, a parabola may be assigned which shall pass through the points B and C, and have nearly the same area with the midship section, and also nearly coincide with the curve; so that the exponent will afford means of ascertaining its relative fulness.

Call the breadth at the water-line AB $= \frac{1}{2}$ B, the depth AE $= h$, and the area ABE $= \frac{1}{2}$M, and let m be the exponent of a parabola having the same area; then

$$\frac{m}{m+1} \cdot \tfrac{1}{2} \mathrm{B} \cdot h = \tfrac{1}{2} \mathrm{M}$$

$$\text{and } m = \frac{\frac{1}{2}\mathrm{M}}{\frac{1}{2}\mathrm{B}\,h - \frac{1}{2}\mathrm{M}} = \frac{\mathrm{M}}{\mathrm{B}\,h - \mathrm{M}} \quad - \; - \; - \; - \quad (5).$$

In the same manner the exponent may be found for the water-line, by supposing a parabola with its vertex at the greatest breadth, and passing through the points in which the water-line cuts the middle line. Suppose the exponent of this parabola $= r$, the length on the water-line $=$ L, and, as before, the breadth $=$ B; also let the area of the water-line $=$ W; then

$$\frac{r}{r+1} \mathrm{L} \cdot \tfrac{1}{2} \mathrm{B} \cdot = \tfrac{1}{2} \mathrm{W}$$

$$\text{and } r = \frac{\mathrm{W}}{\mathrm{BL} - \mathrm{W}} \quad - \; - \; - \; - \; - \; - \quad (6).$$

Lastly, suppose the areas of the several water-lines from the load water-line downwards to decrease in the proportion of the abscissas to a parabola, and let the exponent $= s$, the depth from the water-line to the tangent of the midship section $= h$, the displacement $=$ D, and the area of the water-line $=$ W; then

$$\frac{s}{s+1} \cdot \mathrm{W}\,h = \mathrm{D}$$

$$\text{and } s = \frac{\mathrm{D}}{h\,\mathrm{W} - \mathrm{D}} \quad - \; - \; - \; - \; - \; - \quad (7).$$

By calculating these different exponents for ships already built, and which have been found to possess good qualities, a very correct idea of their shape will be obtained, which, in making new constructions, may be referred to; and after a very short practice, the constructor will be enabled to determine, not only the principal dimensions, but the outlines of the body before a drawing is begun.

A collection of such calculations was begun by Chapman, and has, since his time, been considerably augmented; we now, therefore, know what the value of the exponents ought to be, in the different classes of ships, for the services to which they are destined. It is always found that large ships are fuller than small ones, and, in consequence, have larger exponents;

and that merchant-men have larger exponents than men-of-war of equal size.

The exponent of the line of sections in the Swedish navy, in ships of the line, varies from 2,5 to 2,7; of the midship section, from 5 to 3,8; of the water-line, from 6,6 to 5,9; and of the displacement, from 2,2 to 1,8; of course the larger exponent belongs to the larger class of ships.

In frigates, sloops, and brigs, they are smaller; the exponent of the line of sections varies from 2,3 to 2,1; of the midship section, from 3 to 1,9; of the water-line, from 5,2 to 3,25; and of the displacement, from 1,6 to 1,25. These exponents show that small ships have much larger dimensions in proportion to their displacements than large ones.

The above results were obtained from the displacements and breadths, not including the plank; and the length is that of the construction water-line, which, in Swedish ships, is $\frac{1}{84}$ less than the whole water-line between the rabbets, $\frac{7}{10}$ of which deduction is made from forward, and $\frac{3}{10}$ from aft. In finding the exponent for the water-line, its whole length between the rabbets is taken.

Of course these calculations are equally applicable with the plank on as with it off, in the first-mentioned case the sections near the extremities will have, relatively to the midship section, a larger area, and there will therefore be scarcely any hollow at the ends of the curves, and it will not be improper to take the length of the water-line, the whole length between the rabbets.

The following tables are given as an illustration of this method :—

	Length on the Water-line.	Breadth extreme.	Depth from the water-line to the lower edge of the Rabbet.	Displacement, including the Plank.	Area of the Load-water Section.	Area of the Midship Section.
	Feet.	Feet.	Feet.	Cubic Feet.	Square Feet.	Square Feet.
Nelson....	203,3	53,5	23,5	165182	10027	1099
Bulwark..	180,3	49,0	19,8	105584	7706	791
Endymion.	157,0	41,9	16,0	55807	5656	510

Then from the equations (a), (5), (6), and (7), the following results may be obtained:—

	Value of n, the Exponent of the line of Sections.	Value of m, the Exponent of the Midship Section.	Value of r, the Exponent of the Water-line.	Value of s, the Exponent of the Displacement.
Nelson	2,836	6,9447	11,8034	2,3445
Bulwark	2,851	4,4141	6,8273	2,2538
Endymion	2,300	3,1795	6,1235	1,6088

From this table of exponents, we may judge with certainty of the shape of the vessels. The *Nelson*, for instance, has a very full midship section, and an exceedingly full water-line, but she is not relatively so full towards the extremities as the *Bulwark*, and her displacement is not relatively much fuller than that of the *Bulwark*. The *Bulwark* has a small midship section, is full towards the extremities, and has a very large water section in proportion to her displacement. The *Endymion* is a very sharp ship of her class, has a small midship section, is rather clean towards the extremities, but her water-line is not very sharp; its proportion to her displacement is extremely large.

The four exponents which have been described, will separately only show the degrees of fulness in one direction; but they may be combined in such a manner as to express, at the same time, the longitudinal and transversal fulness; to effect which, the value of the area of the midship section $= \frac{m}{m+1} . \mathrm{B}\, h$ must be substituted in equation (1), which gives

$$\frac{n}{n+1} . \frac{m}{m+1} . l . \mathrm{B} . h = \mathrm{D} \quad - \; - \; - \quad (b);$$

also by substituting the value of $\mathrm{W} = \frac{r}{r+1}\,\mathrm{B} . \mathrm{L}$ in the equation (7), we have

$$\frac{r}{r+1} . \frac{s}{s+1} . \mathrm{L} . \mathrm{B} . h = \mathrm{D} \quad - \; - \; - \quad (c).$$

In these equations the products $\frac{n}{n+1} \cdot \frac{m}{m+1}, \frac{r}{r+1} \cdot \frac{s}{s+1}$ show the relative fulness of different ships, in comparison to the circumscribing parallelopiped. When the construction water-line is equal to the whole water-line, as was supposed in calculating the foregoing table

$$\frac{n}{n+1} \cdot \frac{m}{m+1} = \frac{r}{r+1} \cdot \frac{s}{s+1}$$

By this equation any error in determining the exponents may be detected; and also by using the whole equations (*b*) and (*c*), errors in the dimensions or exponents will be detected.

By a method of interpolation, formulæ of very easy application have been deduced; by which the depth of the centre of gravity of the displacement below the water-section, the height of the metacentre, and several other essential elements, may be approximated to, without the usually long calculations; and thus most of the qualities of a ship, which are determinable by calculation, may be ascertained, compared, and altered, with very little trouble, before the construction is begun.

In order to apply this method of construction to practice, nothing more is requisite than to know the limits between which the exponents generally are for the class of ship in question, the proportion between the principal dimensions, and the distance the centre of gravity should be before the middle of the load-water-line. In Swedish ships of the line, and frigates, the distance of the centre of gravity of the displacement before the middle of the load-water-line, is between $\frac{1}{70}$ and $\frac{1}{80}$ of the length, and in smaller vessels it is a little more, depending on the manner in which their stores and rigging are distributed. This quantity being determined, the weight the ship is to carry, the weight of the hull, and the relative proportions of the different dimensions, or the value of the exponents; the calculations will give the areas of every section, leaving the constructor the power of giving them whatever form he may wish.

By inserting the calculations of a steam-boat which I have very recently constructed according to this method, its application may perhaps be more clearly illustrated.

Suppose the ratio of the breadth to the length to be α, and

that of the breadth to the depth to be β, by substituting them in the equation (b), it will become

$$\frac{n}{n+1} \cdot \frac{m}{m+1} \cdot \alpha \cdot \beta \cdot B^3 = D.$$

The values of m and n are known, being assumed from former experience; the displacement is determined by the weight of the engines, added to the weight of the stores, &c. and an approximation to the weight of the hull. By assigning values to α and β, the value of B is obtained, and from that the values of the length and depth. The dimensions being now known, the scantling may be determined, and the true weight of the hull estimated; which, if very different from the approximation which was used, will cause a corresponding alteration in the dimensions, &c. With a steam-boat, the stability is of minor importance; therefore it is not necessary to refer to equation (c).

The vessel in question is intended for two 25-horse power engines, the weight of which, with the necessary stores and the other articles, was estimated to be about 2050 cubic feet of water, and the approximation which was at first made to the hull was 1850 cubic feet, which supposed the whole displacement to be 3900 cubic feet.

The vessel was intended to be sharp both at the midship section and at the extremities; hence n was taken $= 2{,}12$, and $m = 3{,}0$; the proportion between the length and the breadth, or α, was taken $= 5{,}25$, and that between the breadth and the depth, or β, $= 0{,}32$; by substituting this value in the equation, we have

$$B = \sqrt[3]{\frac{3900 \cdot 3{,}12 \cdot 4}{2{,}12 \cdot 3 \cdot 5{,}25 \cdot 0{,}32}} = 16{,}58$$

$$\text{Length} = 5{,}25\ B = 87{,}04$$
$$\text{Depth} = 0{,}32\ B = 5{,}31.$$

By calculating the weight of the hull according to these dimensions, it was found that the approximation was too small by 175 cubic feet; by adding this quantity to the displacement, and retaining the other values, it will be found from the above equation that the

$$\text{Breadth} = 16{,}822$$

$$\text{Length} = 5{,}25 \,.\, 16{,}822 = 88{,}315$$
$$\text{Depth} = 0{,}32 \,.\, 16{,}822 = 5{,}383.$$

The weight of the engine, its situation, and its centre of gravity, must determine the place of the centre of gravity of the vessel, which was found to be about 2,25 feet before the middle of the length, on the construction water-line; and consequently from equation (2), the situation of the midship section was determined to be 9,27 feet before the middle of the construction water-line.

The stations of the other sections were determined by the room and space. The parameters for the fore and after bodies were first determined by substitution in the equation (3). In the fore body

$$f = \frac{l}{2} - k = \frac{88{,}315}{2} - 9{,}27 = 34{,}887$$

and in the after body

$$f = \frac{l}{2} + k = 53{,}427.$$

The area of the midship section, from equation (5),

$$= \frac{m}{m+1} \mathrm{B}\, h = \tfrac{3}{4} \,.\, 16{,}822 \,.\, 5{,}383$$
$$= 67{,}912 \text{ square feet,}$$

and the half area $= 33{,}956$.

Hence by equation (3) the parameter of the fore body

$$= \frac{\overline{34{,}887}|^{2{,}12}}{33{,}956} = 54{,}895$$

and for the after body

$$a' = \frac{\overline{53{,}427}|^{2{,}12}}{33{,}956} = 135{,}499$$

The calculations for the sections are contained in the following tables:—

For the Fore Body, $x = \dfrac{y^{2,12}}{54,895}$

Sections.		Abscissa or x.	Half the Midship Section — x.
Name.	Distance from the Midship Sec. or y.		
	Feet.	Square Feet.	Square Feet.
End	34,89	33,960	,0
x	32,24	28,730	5,23
u	30,	24,660	9,30
q	24,	15,360	18,60
m	18,	8,349	25,611
h	12,	3,535	30,425
d	6,	,813	33,147
Midship Sec.	0,	,0	33,96

For the After Body, $x = \dfrac{y^{2,12}}{135,499}$

Sections.		Abscissa or x.	Half the Midship Section — x.
Name.	Distance from the Midship Sec. or y.		
	Feet.	Square Feet.	Square Feet.
End	53,43	33,960	,0
34	50,76	30,460	3,50
32	48,	27,060	6,90
28	42,	20,390	13,57
24	36,	14,700	19,26
20	30,	9,990	23,95
16	24,	6,225	27,735
12	18,	3,382	30,578
8	12,	1,432	32,528
4	6,	,329	33,631
Midship Section	0,	,0	33,96

The areas of the sections being thus determined, the construction of the draught was begun. The midship section and one or two sections in each body being drawn in, and their areas ascertained to agree with the tables, one or two diagonals were got in, and the rest of the sections drawn, always keeping their areas precisely equal to those given by the table. The direction of the diagonals, at the extremities, determined the places of the stem and stern-post rabbets, and from that the length of the whole load-water-line was found to be 0,44 feet longer than that of the construction-water-line; viz., 0,33 at the fore end, and 0,11 at the after end; consequently the length of the load-water-line between the rabbets = 88,755 feet.

As in a ship constructed according to this method, the situation of the centre of gravity, with respect to the length, and also the displacement, are known correctly; during the progress of the work much tedious arithmetical calculation is avoided; and after very little practice it will be found that the forms of the different sections may, with great ease, be drawn to contain the requisite areas; and I am confident that by the general adoption of the method, an amazing saving of time and trouble would be effected.

ART. XIX.—*On a Method of improving Timber, by impregnating it with an insoluble Substance; invented by Robert Bill, Esq. Communicated by* JOHN KNOWLES, ESQ., F.R.S., *of the Navy-Office.*

MR. Robert Bill has succeeded in impregnating several kinds of timber with an insoluble varnish, which pieces of large scantling, when dried, readily took up to saturation.

Timber so prepared has been put into a pit filled with carbonic acid gas five years, and thoroughly withstood the fungus rot, while numerous other specimens were destroyed in a fifth part of that time.

Other pieces were placed in the sea at Sheerness; and while wood considered impervious to the gribble worms was nearly eaten up, these remained untouched.

Some specimens of timber so saturated were placed in the earth, half their length being buried, the other half protruding above ground; and pieces cut from the same tree, but unprepared, were put in competition with them: at the end of five years the former were unchanged, the latter entirely destroyed.

It is obvious from these experiments, that the inferior kinds of timber may be made, at a small expense, more durable than oak, or perhaps any known wood; from which great national benefits may be derived, as there is no limit to the uses to which saturated timber may be applied.

ART. XX.—*On the Displacement of a Ship, when relatively in Motion with respect to the Water.*

IN a former paper (Art. 2) the volume of water that a ship displaces, when both the ship and the water are at rest, is said to be equal to the weight of the ship, agreeably to a well-known principle of floating bodies. In still water, the pressure of a particle at any given depth is equal to the weight of the superincumbent particles, and is the same in all directions. The vertical pressure of all the particles in contact with the surface

of the floating body, supports the body as it did previously the volume of water which it has displaced; and as the equilibrium is continued, the weight of the body must be equal to the weight of the displaced water.

This relates, however, only to the circumstances of a ship at rest in still water, or of a ship and the water moving in the same direction with the same velocity, in which case the ship is still relatively at rest.

When the ship and the water are relatively in motion, either by the ship being at rest and the water in motion, or by the ship's moving and the water's being at rest, or by the ship's and water's moving with unequal velocities or in different directions, the depth to which the ship sinks must be determined in connexion with other considerations. The fact of a ship's "sinking several inches deeper in the water when at anchor in a strong tide-way, or at sea under press of sail, than when at anchor in still water," was mentioned in the communication (Art. 16) of our correspondent NAUTILUS. M. Romme also observed, that a frigate, which was lashed to a sheer hulk in the river Charente, sunk two inches more when the velocity of the stream was great than when the motion of the stream was only just sensible.

Romme, in his '*L'Art de la Marine*,' (page 26,) describes some experiments he made to determine the vertical pressure of water when in motion compared with its pressure when at rest. He had two tin tubes made, the one (Fig. 12) straight as *a b*, and the other curved as *c d e*, each open at its ends, and capable of receiving a float *g f*, the lower part of which, *f*, was of cork, and the upper part a rod marked with inches and lines. These tubes, containing their floats, were first plunged into still water, and the division of the rods observed, corresponding with the upper orifices of the tubes. The tubes were then placed in running water, the current being in the direction *h i*, and the bent tube *c d e*, with its lower end, turned in the same direction; the floats in both tubes were then observed to have sunk an inch below the position they had when the tubes were in still water. The bent tube was then turned so as to present its orifice to the current, when the float rose an inch above the position which it had in still water. The bent tube

was then placed with the lower end perpendicularly to the direction of the current, when the float sunk an inch below its position in still water. He measured the velocity of the current, and found that the water ran 70 feet in 30″, or that its velocity was that due to a height of an inch and a line nearly; which corresponded with the distance the floats in the tubes rose or fell in the experiments. Other experiments in currents of different velocities produced similar results. In some instances the depression and elevation of the floats were as much as five or six inches, being always the height due to the velocity of the current. He ascertained, also, that the results were the same, to whatever depth the tubes were plunged into the water.

Suppose the depth to which the tubes are plunged into the water to be represented by k; then the vertical pressure of the water at the orifice b of the straight tube, when the water is at rest, is in proportion to this depth, and causes the water in the tube to rise to the level of the surrounding water; but when the water moves with a velocity due to the height z, the particles no longer press equally in all directions, having a greater tendency to motion in the direction of the current than in any other; so that the vertical pressure of the particles at the orifice b is less than before, and by the experiment is found to be proportional to $k - z$.

In the application of the result of this experiment to a floating parallelopiped, whose sides are perpendicular, and whose upper and lower surfaces are parallel to the water's surface, the pressure of the water on the sides being horizontal, has no effect in supporting its weight, and the vertical pressure of the particles of the water on the lower surface, being less when in motion than when at rest in the proportion of k to $k - z$, k being in this case the perpendicular distance of the lower side of the body from the water's surface, and z as before, the height due to the velocity of the current, the parallelopiped will sink deeper in the running water than in the still water in the same proportion: that is, the perpendicular depth of the immersed part of the body will be $k + z$, having sunk deeper the distance z.

When the bent tube $c\,d\,e$ is placed with its lower end in the

direction of the stream hi, the effect is the same as with the straight tube; the particles of water at the orifice e, pressing less on the particles in the tube when the water is in motion than when at rest, the water in the tube is not equally supported; so that it sinks below the level of the surrounding water, a distance found by the experiment to be equal to z, the height of the water in the tube being $k - z$. The effect is the same also, when the lower end of the bent tube is placed perpendicularly to the current; but when placed with its orifice presented to the direction of the current, the particles of the water in motion exert a pressure at the orifice e, greater than they would when at rest, in consequence of the velocity in the direction of their motion, which causes the confined water in the tube to rise above the level of the surrounding water, a height found by the experiment to be equal to z, the height of the water in the tube being $k + z$.

Now as the water rose a distance z above the level of the surrounding water, when the lower end of the bent tube was placed exactly in the direction opposed to the current, and fell the same distance z below the level of the surrounding water when the lower end of the tube was placed perpendicularly to the direction of the current, there must be an angle at which the tube might be placed with respect to the direction of the current, at which the water in the tube would be at the same height as the surrounding water. Taking any line v in the direction of the current to represent its velocity, which is wholly effective in raising the water in the tube when placed in the opposite direction to the current the distance z, and which has the effect of depressing the water in the tube the same distance z; when placed perpendicularly to the direction of the current, the angle at which the tube must be placed, in order that such a part of this velocity may be effective in causing the water in the tube to rise exactly to the level of the surrounding water, may be found by supposing that at this angle the effective part may be equal to $\frac{1}{2}$ v, which, by the resolution of the directions of the pressures, makes the angle at which the tube must be placed 60° with the direction of the current.

In the application of this reasoning to the determination of the vertical pressure of the water in motion on a ship's body,

the pressure on the fore and after parts of the body must be considered separately; the greatest transverse section, called the midship section being the division between these parts.

The expression representing the pressure of the water on the fore part will be composed of two terms, the one expressing the pressure on the part of the body where it is greater than it would be if the body were at rest, and the other the pressure on the part of the fore body, where it is less than it would be if the body were at rest. The line of division, which we will call the neutral line, being the line on the fore part of the ship's body, at which the pressure of the water is neither increased nor diminished by the velocity of the water, will be a curved line, depending on the form of the ship's body, but always before the greatest transverse section. In regular figures, its position and form may be determined either geometrically or analytically; but in ships, can be found only by trial and calculations. In the expression for the pressure of the water on the part of the body contained between the neutral line and the midship, the pressure represented by the proportional depth k will be increased by a function of z; in the expression for the part of the fore body contained between the neutral line and the midship section, the pressure represented by the proportional depth k will be diminished by a function of z; and in the after body, $k - z$ will be the element representing the pressure.

Let $a\,b$ (Fig. 13) represent an element of the ship's body, and $c\,b$ the direction of the motion and the height due to the velocity of a particle of water, which meets this element. By resolving $c\,b$ into $c\,d$ and $d\,b$, $c\,d$ which is perpendicular to $a\,b$, is supposed to be destroyed, and the particle of water glides along the surface of the ship's body with a velocity $d\,b$. Let $c\,b$ be equal to z, and the depth of the particle below the surface of the water be equal to k, and the angle $a\,b\,c$ equal to i; then $d\,b = z \,.\, cos \,.\, i$. The pressure of the particle of water on the part of the fore body before the neutral line will then be proportional to $k + z \,.\, cos \,.\, i$; the pressure of the particle of water on the part of the fore body between the neutral line and the midship section, will be proportional to $k - z \,.\, cos \,.\, i$; and the pressure of the particle of water on the after body will be

proportional, according to the experiment on the bent tube, to $k - z$.

Suppose the ship to be placed with its fore part opposed to a current, the direction of which is that of the ship's keel, and the velocity of which is that due to the height z. Suppose the surface of the ship's body below the surface of the water to be divided into an infinite number of small surfaces; let x be the horizontal distance of one of these small surfaces from the midship section, and y its transverse distance from the longitudinal vertical plane dividing the ship into two equal and similar parts, and k its distance from the plane of floatation. The projection of this small surface on the plane of floatation is $dx \,.\, dy$; and representing the specific gravity of the water by P, the pressure of the water on this small surface, in a vertical direction, in the after body, is $P\,dx\,.dy\,.(k - z)$; and the vertical pressure of the water on a small surface, in the part contained between the midship section and the neutral section in the fore body, is $P\,dx\,.dy\;(k - z\,.\cos.i)$; and the vertical pressure of the water on a small surface in the part of the fore body before the neutral section, by taking x for the distance of this small surface from the neutral section, is $P\,dx\,.\,dy\,.\,(k + z\,.\cos.i)$. The vertical pressure of the water on the whole of the fore part of the ship's body (taking both sides of the ship), is therefore

$$2\,P\int dx \int dy\,.(k + z\,.\cos.i)$$

$$+\ 2\,P\int dx \int dy\,.\,(k - z\,.\cos.i)\,;$$

and the vertical pressure of the water on the whole of the after part of the ship's body, is

$$2\,P\int dx \int dy\,.\,(k - z).$$

The sum of these terms,

$$2\,P\int dx\,.dy\,.\,(k + z\,.\cos.i) + 2\,P\int dx \int dy\,.(k - z\,.\cos.i)$$

$$+\ 2\,P\int dx\,.dy\;.\,(k - z),$$

is the total vertical pressure of the water on the ship's body, lying opposed to a current, whose velocity is that due to the height z.

If the water were at rest, the total vertical pressure of the water on the ship's body, supposed to be sunk to the same depth below the surface of the water, taking x for the whole length of the ship, would be $2\,\mathrm{P}\int d\,x \int d\,y\,k$. In this expression x is equal to the sum of the three lengths expressed by x in the former expression. This quantity representing the vertical pressure of the water on the ship's body when at rest, is evidently greater than the quantity representing the vertical pressure of the water on the ship's body when in motion, in consequence of the first term of the expression

$$2\,\mathrm{P}\int dx \int d\,y\,.\,(k + z\,.\,cos\,.\,i) + 2\,\mathrm{P}\int d\,x \int d\,y\,.\,(k - z\,.\,cos\,.\,i)$$
$$+\ 2\,\mathrm{P}\int d\,x \int d\,y\,.\,(k - z),$$

which is less than the sum of the two other terms, being increased in a less proportion by the addition of $z\,.\,cos\,.\,i$ to k, than the sum of the last two terms is diminished by $z\,.\,cos\,.\,i$ being subtracted from k in the first, which is the smaller of the last two terms, and by z being subtracted from k in the last term. The vertical pressure of the water, therefore, being less on the ship's body when placed in a current than in still water, estimated to the same draught of water in both cases, the ship must sink deeper in the current than in still water. The distance it sinks depends on the value of z, the height due to the velocity of the current, and i, representing the different angles at which the particles of water strike the ship's body, which depend on the form of the body. Supposing the values of all the terms known, and subtracting the expression for the vertical pressure of the water in motion on the ship's body, from the expression for the vertical pressure of the water at rest, estimated at the same draught of water in both cases, the remainder will be the quantity to be taken from the expression for the vertical pressure of the water at rest, measuring from the line of floatation downwards, which determines the distance which the ship will sink deeper in water in motion than at rest.

This expression represents the vertical pressure of the water, under the consideration that each particle of the fluid in motion

impinges on the surface of the ship's body; neglecting the circumstance of those particles which meet the body at the middle of the fore part, escaping along the surface of the body, and preventing many of the particles further removed from the middle from impinging on the surface, and communicating their action to the body only through the medium of those particles in contact with it; the particles still further removed from the middle, communicating in the same manner their action to the body through the medium of a greater number of intervening particles. The investigation is conducted with immediate reference to the results of the experiments with the tubes, instead of forming an independent theory on the hypothetical action of fluids on floating bodies. The division of the fore part of the ship's body into two parts, by the section at the lines on the surface of the body, at which the effect of the pressure of the water in motion is the same as that of the pressure of the water at rest, is introduced by the writer of these remarks, as being directed by the results of the experiments with the bent tube; considering that the whole pressure of the water on the fore part is not increased by the motion of the fluid, but only the part before the neutral section, the pressure on the remainder being diminished.

The vertical pressure of the water on a ship's body may be determined on the same principles, but with more difficulty, when the direction of the ship's length makes any angle with the direction of the current of the water.

It may be observed, that the alteration occasioned in the vertical pressure of the water in consequence of the relative motion of the ship and water, affects the determination of the stability of the ship, which is measured by the vertical pressure of the water multiplied into the distance it acts from the longitudinal axis passing through the centre of gravity. The connexion of the common theory of the stability of ships, however, with this principle, although requisite for the correct determination of the absolute stability of a ship under sail, is by no means necessary for the determination of the comparative stability of ships, which is generally required to be known.

M.

Art. XXI.—*On the Defects caused in Ships' Bottoms by Marine Animals, with Descriptive Remarks on some of the most Destructive Kinds; by* Mr. Willcox, *of His Majesty's Dockyard at Portsmouth.*

It is generally observed, in the examination of ships in dock, whenever the copper is found to have been materially decayed, or beaten off any part of the ship's bottom, that the plank is injured by the attacks of marine animals.

In some climates, (particularly in the East and West Indies, on the coast of Africa, and in the Mediterranean,) the destruction of the timber is found to be much more rapid than in others, from the abundance of these animals which there infest the seas. The danger to be apprehended from them there is very great;—and indeed, it is every where unsafe to allow any part of the bottom of a ship to remain unprotected from their attacks. Many methods of covering the surfaces of ships' bottoms with protecting substances have been proposed, but nothing has been yet found to answer so well as copper sheathing.

The most destructive of the marine animals are, the Teredo, the Pholas, and the Lepisma; of these three, the most destructive is the Teredo. This genus is said to have been originally imported from India. They penetrate the hardest wood, and gradually increase in size as they proceed in their devastation, making such havoc, that the part which is attacked by them frequently becomes like a honeycomb. It is, however, rather an uncommon circumstance for them to bore through, although they approach the interior surface within a very small distance, after leaving a substance not thicker than the twentieth part of an inch from the inside. Such circumstances must be attended with the probability of serious consequences, as the natural effects produced by the action of the water on such reduced parts, must in a short time open a passage into the ship.

An instance occurred in the case of His Majesty's ship Sceptre, of seventy-four guns, which fully proved the danger caused by their attacks: she left Bombay, destined for Eng-

land, in 1807, and after being some time on her passage, was obliged to return in consequence of a serious leak, which was found to have proceeded from the bow; and on her being examined, it was ascertained to have originated in consequence of some of the copper having been rubbed off, and the parts of the bottom and the gripe thereby exposed, having been attacked by the Teredo, which had penetrated these places to such an extent as to render her quite unsafe to pursue her voyage, without putting new plank on the bottom, and shifting the gripe.

The writer has many opportunities of examining these destructive animals, in their various stages of existence. His observations have in many cases agreed with the accounts given by Turton, although, in some respects, he is led to differ from that naturalist.

The species of the Teredo most commonly found in ships' bottoms, is the Teredo navalis. The shell is a tube, more or less thin, semitransparent, white, smooth, tapering until the animal is at its full size, length frequently found several feet, the tube very irregular in form, and extends as the animal advances, which continues to bore as long as the aliment is suitable to its life. To the head of the animal, Turton says, are attached two hemispherical valves, which are "very convex, both sides tapering longitudinally, or from the hinge to the front margin to an obtuse point, giving them a triangular appearance; on one side of each, close to the hinge, is a somewhat triangular projection, which is regularly but rather remotely striate transversely; behind this is a narrow space, minutely and closely striate longitudinally in straight lines; the remaining surface irregularly striate in a curved direction; on the opposite side, close to the hinge, is a smooth rounded projection, defined on the under-side by an oblique longitudinal ridge, inside white, glossy, with a thick knob at the termination of the smaller end; hinge with a long slender curved tooth in each valve, placed interiorly as in the Pholas, besides a tooth-like projection seated upon the hinge, which in one valve terminates in a small reflected lamellar point, locking into the opposite valve." These valves are supposed by this author to be attached to the cylindrical tube; this, however, does not appear to be the case: for

if a piece of wood which contains these animals be split, the valves may be discovered in a perfect state a little beyond the tube, unconnected; and by inserting the point of a penknife between the valves, the animal may easily be drawn out, without any apparent injury. The tubes are formed of a calcareous secretion, and are useful in affording to the animal an easy and smooth passage; they also prevent the encroachment of the animals on each others' courses, the holes being so numerous and the interstices of the wood consequently so very thin, that without the defence afforded by these tubes, their passages would break into each other.

The hemispherical valves at the head of the animals are surrounded by a white gelatinous substance, which they discharge at pleasure, and which possesses a solvent power over the wood, and lessens the friction, while making their volutions, or perhaps semivolutions, cutting or scooping away the wood thus partly decomposed. This aliment undergoing a preparation, forms a secretion which becomes consolidated, and composes the tube as the animal advances. If these valves, which are similar to each other, and resemble exactly the cutting part of a round-nosed auger, make complete volutions, one valve only can be effective, which must be extended before the other. From this circumstance, and from their similarity, it appears probable that semivolutions take place, both valves being then effective by their extension alternately; by which the animal would not be required to turn round, which, from its apparent deficiency in muscular strength, it is probably incapable of doing, without being twisted up. I have seen several of those animals, after separating wood which contained them, drawn up in the manner that a leech will contract itself, by which means they completely filled and pressed hard against the sides of the tube, which greatly facilitated their forcing forward in the performance of their labour. The termination of their courses is always spherically concave.

The supposition that the destruction of the wood is chiefly by actual mechanical action, is agreeable to the opinion of Sir Everard Home, in his remarks on this animal, in the Philosophical Transactions for 1806, who appears to have mistaken the term of centre-bit for the auger-bit alluded to, the centre-bit

always making the termination of the hole, when boring, abruptly truncate, and the auger-bit hemispherical.

There may be observed by a careful examination, on the exterior surface of wood which contains these animals, small lumps of a gelatinous substance, which I suppose to be the young of the animal; and when taken off, there may frequently be seen the commencement of a small hole in the wood, having the appearance of those made by the animal in question at their entrance.

Turton mentions tubes protruding, from a quarter of an inch to an inch and a half beyond the surface of the wood, but does not assign any reason for such appearance. Many opportunities have been afforded me of breaking off parts from such tubes, some of which have been as much as six or seven inches in length, but very different in form, tapering to the size spoken of at the entrance of the animal, with a small aperture in the end, white, and semitransparent; others with their ends much larger, and open, with a laminated interior; some of them forming rings, six or seven in number, with one side projecting a third across the tube, which may have been occasioned by some obstruction the animal may have met with, and may not be a general character of the tubes. Others of the same size at their ends had the inside quite plain, and perfectly smooth. Those tubes with large apertures, may probably have had their ends broken off by some accident, as the outer end of the tube, when perfect, is almost invariably found to be very small.

The protrusion of the tubes is occasioned by the wood they were lodged in having been rotten and washed away, or destroyed, by the ravages of a most destructive marine insect, which will be mentioned hereafter.

A short time since, I observed on board a merchant ship, in a piece of round African timber, which was ten inches through and seven feet long, about thirty holes in its ends, of an unusual size, some of which were an inch in diameter, bored as I suppose by the Teredogigas. The captain informed me that this piece of wood had been used as a fender, for the protection of the side of his ship, while he was taking in his cargo of timber on the coast of Africa. After having had several pieces cut off

transversely, the remainder, which was about five feet long, was split to pieces, to ascertain the length and structure of the tubes, and also the probability of finding some hemispherical valves of a remarkable size. No valves were, however, found; many of the holes ran from end to end, and others, entering at the exterior surface, then took the direction of the fibre, and passed out at the end. All the holes were lined with the tubes, which were in a perfect state.

The Pholas is another remarkable genus of these destructive animals. The species striata is more generally found in the bottoms of ships than others of the same genus. It will answer the following description:—"Shell white, oblong, or conic, rounded and obtuse at the larger end, which is rough with raised curved lines and nearly closed, the frontal margin folding back and forming a smooth surface around it; the narrower end gaping and striate both longitudinally and transversely; hinge with a somewhat heart-shaped plate at the back, the point of which is upwards, beneath which is a long narrow one connecting the valves; in front is a plate on each side the opening, and a third narrow one down the middle; teeth long, slender, curved; length half an inch; breadth nearly an inch."

This animal is not only found buried in timber under water, but also in stones, clay, &c. This species emits a viscous humour, which partially decomposes the material they inhabit, by its solvent properties.

The animal bodily advances and recedes a short distance, sometimes turning half round, which action assists in the enlargement of the cavity. The wood which is taken away by the animal, is thrown out through the posterior compartment of the trunk in small pieces retaining the general appearance of the wood.

It is said the presence of the atmospheric air is necessary in forming the solvent, the oxygen of which, combining with the secretion, forms phosphorous acid, which effects a decomposition of the material the animal inhabits. This, however, appears doubtful, as in many instances specimens of the Pholas are in my possession, which have been cut out of the keels of ships, where atmospheric air can have been but very rarely present.

They make their attack in a similar manner to the Teredo, by burying when young; the holes at their first entrance being not more than a quarter of an inch in diameter; the animal increasing in growth as it advances, and when at maturity ceasing to bore, as it does not obtain its sustenance from the wood, as the Teredo, but from the inhabitants of the water. The holes which contain them are little larger than themselves, and perfectly conical, which prevents their being extracted whole, except by cutting away the substance in which they are buried, the depth of which is seldom more than will enable them to protrude their proboscis to the surface nearest the water.

The Lepisma is an insect (before alluded to), which, though small, is extremely destructive.

It preys on wood, and is known to seize upon it immediately after being immersed in sea-water. The bottoms of ships, where the copper is rubbed off, are frequently attacked by great numbers of them; in some cases they collect so closely together, that the space of two inches square serves two or three hundred to prey on.

These insects are so numerous in the East Indies as to render it necessary to get unprotected boats taken out of the water, when not in use, in consequence of the bottoms having been known to be eaten through in so short a time as three or four weeks.

The copper sheets, which are commonly used for the protection of the bottoms of ships from the attacks of these animals, are known to vary greatly in point of durability, either from a difference in their purity, or from other causes not very easily to be accounted for.

Not only does the copper on one ship's bottom often last good more than twice as long as the copper on another ship's bottom; but even some of the sheets on the same bottom are frequently found to be decayed so as to have holes through them, while others adjoining or very near them are in a good state. The causes of the very great difference frequently observable in the sheets of copper on the same ship, may be, that the impurity of some sheets, by a mixture of some other metal with the copper, by galvanic action, may be the

means of their being destroyed, while other sheets in the vicinity are thereby preserved, agreeably to the principle on which Sir Humphry Davy recommended the use of iron or zinc plates to be secured on ships' bottoms as a protection of the copper.

The circumstance of so great a difference in this article has called the attention of most that are concerned in the manufacturing of it; by which means it may be expected that copper sheets may be produced, which shall have more uniformity and durability than any that have been hitherto in use.

Copper being sometimes found to have holes in it, in as short a time as two years, while the principal part of the copper on the bottom may generally last at least seven or eight years, if the ship be not brought into dock till the expiration of that period from any other cause, a considerable time will have elapsed that the plank of the bottom, where the copper was decayed, will have been exposed to the attacks of these destructive animals.

Planks on the bottom of a ship where the copper has been either decayed or worn through, have been found to have been penetrated very nearly through by the Teredo navalis. I have known an instance in which it was found necessary to shift several planks, on account of their being nearly eaten through a few inches below the water-line. This suggests the propriety of having the timbers of the frame of all ships filled in and caulked, as is the custom in His Majesty's ships; and if the fillings were carried up as high as the load draught of water, it would render the danger arising from the attacks of these animals much less.

It may probably be considered advantageous to cover the bottom of ships more generally with felt instead of tarred paper, which is commonly used, but is objectionable in consequence of its susceptibility of absorbing water; and when in this state it soon becomes rotten; and where it is exposed to the action of the fluid from the copper being off, it is very soon washed away, leaving the plank uncovered. The advantage of felt on ships' bottoms, consists in its being impervious to water, and, by its adhesiveness, stopping many of the casual leaks,

and from its being also impervious to the attacks of the marine animals which are destructive to ships' bottoms.

If the bottoms of ships were sheathed with board over the felt, and caulked, it would be an additional security, and effect a better contact with the felt and the plank. In the event of copper being broken or rubbed off by any accident, the sheathing would protect the felt from being torn, and the plank of the bottom by this means would be guarded.

The expense, however, of sheathing is a great objection to it. The least objectionable method of giving ships' bottoms full protection from the danger caused by these marine depredators, is probably the filling in and caulking between the timbers of the frame, as high as the load-water section.

Art. XXII.—*Remarks on Chapman's Theory of the Resistance of Fluids: by* Mr. W. Henwood, *Naval Architect.*

Every theory of the resistance of fluids rests upon an assumed basis, the eligibility of which must be proved, by the agreement of the principles deduced from it, with the results of experiment. The object of this paper is to inquire into the accuracy of the conclusion at which Chapman has arrived, in his Treatise on Ship-Building;—that there is an accordance between his theoretical deduction and what takes place in practice. In order to calculate the resistance a ship experiences when moving in the water, it is usual to divide the immersed part of the bottom into triangles, and to compute the resistance on each. The resistance on the fore body of a ship is called positive, and that on the after body negative; the whole resistance is the sum of that on all the triangles, or the sum of the positive and negative resistances. It is highly probable, if not certain, that the effect of the resistance of the water on the fore part of a ship in motion is not the same, or equal to that on the after part; so that if equal areas be taken towards the head and the stern of a ship, inclined at the same angle to the direction of the ship's motion, the resistances on

those areas will not be equal; or, supposing the fore and after bodies of a ship to be similar and equal, the positive resistance on the one will not be equal to the negative resistance on the other. To establish some relation between the positive and negative resistances, Chapman has assumed, that when a ship is in motion, the water before the greatest breadth is driven ahead, or has a motion in the same direction as the ship, and that the water abaft the greatest breadth moves in the opposite direction. According to this hypothesis, the relative velocity of the water and ship forward is less than abaft. It is difficult to imagine how this can be, or how the water abaft the midship section of a ship can possibly move in a direction opposite to that of the ship's course. At the instant a ship is moved ahead from one point of space to another, a separation must take place of the stern from the water; and a void must be produced, which probably is filled up much too quickly to admit of its being observed. It does by no means follow, there is not a void space at the stern of a ship, when moving rapidly in the water, because it cannot be strictly perceived; nor that the water surrounding the sides does not move in the same direction as the ship, because it apparently moves the opposite way. The manner in which water rushes into an empty dock, when by its pressure it bursts the gates, makes it in some measure evident that the void space which a ship occasions by moving ahead is filled by the fluid rushing in from abaft, or from where the vacuity begins to be formed; and that the velocity with which the water at the stern fills the vacuum which the ship occasions, is never small in comparison with the velocity of the ship; and it may, in all circumstances, be much greater. If such is the fact, the whole of the water contiguous to a ship must have a motion in the same direction as the ship, and part of it cannot run ahead of the ship and the remainder the contrary way.

Upon the above hypothesis, Chapman has founded the distinguishing principle of his theory, which subsequently he has endeavoured to show is requisite to be included in a computation of the resistance on the bottom of a ship. From the ratio of the assumed velocities of the water afore and abaft the greatest breadth, he concludes, that in order to obtain the true

resistance of a ship, the sum of the resistances on the triangles of the fore body must be multiplied by 6, and the sum of those of the after part by 7, and the sum of these products be divided by 13. He applies this principle in determining the mean direction of the resistance on the bottom of a ship, when sailing by the wind,—in order to find where the common centre of gravity of the sails should be placed with respect to the length. Having calculated the position of the centre of gravity of the sails of the same ship, and made some allowance for the bending of the masts, and for the distance which, he says, the centre of effort of the wind on the sail must be carried towards the lee-side,—on account of their curvature, the wind forming a kind of bag in them, more on the lee-side than on the weather-side,—and which distance he supposes to be about six feet; he finds the mean direction of the resistance of the water, when the positive and negative resistances are multiplied by 6 and 7, passes very near the centre of effort of the wind on the sails. He considers this proximity in an approved ship, of the direction of the resistance of the water on the bottom, and the position of the centre of effort of the sails, a strong confirmation of the accuracy of his principle,—that in calculating the resistance of the water, the positive part should be multiplied by 6, and the negative by 7, and the sum of these products be divided by 13. When the resistances are not multiplied by 6 and 7, the mean direction of the water passes 2,75 feet afore and to windward of that line, which Chapman considers the true direction. He concludes the mean direction of the water cannot possibly pass so far forward; because if it did, it would be necessary to keep the rudder at an angle of about 15°, with the middle line of the ship; which is found, by experience, not to be the case in ships similar to that on which Chapman made his calculations. If the remarks on page 47, of No. 1 of 'Papers on Naval Architecture,' are well founded, the statement of Chapman—that the centre of effort of the wind on the sails must be carried some distance towards the lee-side, when a ship is sailing by the wind—is certainly erroneous. It appears from the remarks referred to, that when a sail receives an oblique impulse, the centre of effort of the wind upon it is always situated on the weather-side of its centre of gravity, and

consequently the centre of effort of all the sails must be on the windward side of their common centre of gravity. If the centre of effort of the wind on the sails, instead of being about six feet to leeward, as Chapman supposes, is situated on the windward side of the centre of gravity, that line, or mean direction of the water, which Chapman concludes is the true one, must be much farther off from the centre of effort of the wind on the sails than that line or direction is, which, according to Chapman, cannot be the true one. It seems, then, that when in calculating the mean direction of the water, the positive and negative resistances are *not* multiplied by 6 and 7, a much nearer approximation to the true direction of the water is obtained, than when the coefficients 6 and 7 are made use of. It appears, also, the hypothesis admitted respecting the opposite directions of the streams of water at the sides of a ship, is unsupported by Chapman's conclusions.

ART. XXIII.—*On calculating the Tonnage of Ships.*

THE propriety of having some scale by which the magnitude or capacity of ships may be compared with one another under one point of view, is universally acknowledged. Different causes, according to the services to which ships are applied, conduce to the propriety of a true method of comparison. If the number of guns a ship o war carries be correctly stated, and subject to no variation, and the number of guns should bear a constant relation to the magnitude of the body, the designation of a ship according to the number of guns might be sufficient for general purposes; as ships of war require chiefly to be compared with respect to their force.

The tonnage is generally used as a measure, by which ships built by contract are paid for. In order that this method of estimating the value of a ship might be correct, the relative alteration of any dimension should alter the tonnage in the same proportion, as it would affect the expense of building the ship. By the present method of measuring the tonnage, the increase of the breadth of a ship increases the tonnage in a

much greater proportion than the expense of building. Though other rules may be given for calculating the tonnage of ships, which may be less incorrect as a scale of payment of building, than the one at present in use, yet, as no correct analogy can be established between the tonnage and the expense of building, it appears desirable that some other scale of payment should be adopted, founded on more correct principles. If any part of the displacement of a ship be taken as a measure of the expense of building, it appears more reasonable that the weight of the hull, which is determined by the light displacement, should be taken, than the part of the displacement which is brought into the water by the lading. A better scale of the expense of building ships even than this may probably be determined by attention to this particular object, there being certainly no necessity that the same scale of measurement should be used for the lading and the expense of building.

The disadvantage of paying for ships in proportion to their tonnage, is, however, no doubt, in a great degree corrected by a full examination of the design, previously to the settlement of the contract. In merchant-ships, however, this mode of payment is in numerous instances found to be injurious, by being the means of too little breadth being given to them, in order to reduce the tonnage, and thereby lessen the expense of building.

A correct method of calculating the tonnage, although desirable for all ships for the sake of uniformity, is particularly necessary for merchant-ships, which should always be compared by the true quantity of lading they can carry, in correct proportion to which their dues should be paid. The tonnage should be the correct measure of the number of tons of the lading of a ship. This is the weight that will bring a ship down in the water from the light water-line, at which it swims when properly equipped with every thing on board except the lading, to the load-water-line, at which it swims when laden.

This may be correctly found by determining the solid content of the body between the light and load-water-lines, the weight of which, considered as sea-water, is the true lading; this solid divided by 35, the number of cubic feet of sea-water in a ton, gives the true tonnage, or weight of the lading.

The rule commonly used in England does not even approximate, on correct principles, to the true tonnage; the elements of the calculation being erroneously taken, the half-breadth of the ship being substituted for the mean depth from the load to the light draught of water, and the divisor 94 substituted for 35, as a correction, though a very inadequate one, to this error.

Among the methods that have been proposed for the determination of the tonnage of ships, that of Chapman, in the 11th chapter of his '*Traité de la Construction des Vaisseaux,*' is founded on the true elements of the calculation; it has, however, this serious disadvantage,—that different divisors are taken at the will of the person who makes the calculation, according to his judgment of the relative fulness of the body between the load and light draughts of water.

That there would be considerable trouble in obtaining the correct tonnage of all the ships of the merchant navy, must be admitted;—of the ships of the Royal Navy the trouble would be much less, as it could be calculated from the drawings by which they were built, which are always preserved in the Navy Office. But the correct tonnage, even of all merchant-ships, might be obtained in a few years; and when the tonnage of the ships now afloat should be known, the great difficulty would have been surmounted, as the tonnage of every new ship could be calculated with comparatively little trouble. A scale of tonnage (see page 11) should be calculated for every ship, previously to its being launched, either from the drawing (if built from one) or from the ship itself. The light water-line might be determined when the ship is fully equipped, with every thing on board except the lading, and transferred to the scale of tonnage previously made; the tonnage between this and the load-water-line would be the true tonnage, or weight of lading of the ship. The lading on board, when the ship swam at any intermediate line between the light and load-water-lines, would be immediately known by reference to the computed scale.

If it be objected, that many persons who are now capable of measuring the tonnage of ships would be unable to make these additional calculations, it may be answered, that as the number

required to perform this service would be but small, sufficient persons might be found from those at present employed in this work, fully competent to undertake it;—and indeed, that the calculations are so simple, that all might soon be perfectly acquainted with them.

Atwood gives, in his paper on the stability of ships, in the Philosophical Transactions of the Royal Society of London, for 1798, (page 301) the tonnage of the *Cuffnells*, an East Indiaman, between the load-water-section and six successive horizontal sections below it, at two feet apart. The total displacement of this ship he determines to be 3410 tons.

The water-section, No. 12, is the load-water-section.

From the Water-Section.	Difference of Tonnage.	From the Water-Section.	Difference of Tonnage.
12 to 11	377 tons.	12 to 11	377 tons.
11 to 10	374	12 to 10	751
10 to 9	367	12 to 9	1118
9 to 8	357	12 to 8	1475
8 to 7	348	12 to 7	1823
7 to 6	333	12 to 6	2156

From these calculations a scale of tonnage may be formed, by which the weight of lading which would bring down this ship any distance between the load and light draughts of water may be immediately found.

The following method of calculating the tonnage of ships, although by no means superseding the propriety of scales of tonnage, may be considered superior to the rule at present in use, being founded on the true elements of the tonnage, the length, and breadth of the ship, and the depth between the load and light draughts of water, and approximating very nearly to the true tonnage.

Let ab (Fig. 14) represent the load-water-line, and cd the light water-line; take the arithmetical mean of ac and bd, which call e; let the length of the load-water-line, ab, be taken from the fore part of the rabbet of the stem to the after part of the rabbet of the stern-post, which call f; and let the greatest breadth at the load-water-line be represented by g. Multiply these three quantities together; then $\frac{x}{y}.efg$ will be

the tonnage, in cubic feet, of sea-water, $\frac{x}{y}$ representing the fraction expressing the proportional part of the whole solid.

By obtaining the correct tonnage of different ships, by rules for calculating the contents of solids, (page 10,) it is found that $\frac{3}{4}$ may be substituted for $\frac{x}{y}$, subject to certain corrections, determined by reference to the ships whose tonnage is required. This correction may be most easily applied when reduced to a per centage, according to the different degrees of fulness of the part of the body contained between the load and light water-lines, which may be determined by the following method :—

Draw ef parallel to ab, and at a distance below it equal to half the mean of ac and bd, and let gth (Fig. 15) represent the horizontal view of this section; divide the whole length gh into eight equal parts, and at the points of division draw iq, kr, ls, mt, nu, ov, and pw, perpendicular to the middle line gh. Take the sum of the lengths of these seven ordinates, and add to the part of the tonnage already found $1\frac{1}{2}$ per cent. for every one per cent. that this sum exceeds six times the length of the longest of these ordinates. This will give an approximate value of the tonnage to a great degree of accuracy.

Rule.

Take the length of the ship from the fore part of the rabbet of the stem to the after part of the rabbet of the stern-post at the height of the load-water-line, the greatest breadth of the ship at this height, and the mean depth between the light and load-water-lines; multiply these three dimensions together, and take $\frac{3}{4}$ the product, and divide by 35.

Then divide the length of the ship at half the mean depth between the light and load-water-lines into eight equal parts, take the sum of the lengths of the seven half-breadths to the outside of the ship, and add to the above quantity $1\frac{1}{2}$ per cent. for every one per cent. this sum exceeds six times the length of the greatest of these half-breadths.

The result is the tonnage, or the weight in tons, that will be

required to bring the ship down in the water from the light to the load-water-line.

EXAMPLE.

	Feet.
Length of a ship of 80 guns, from the fore part of the rabbet of the stem to the after part of the rabbet of the stern-post, at the height of the load-water-line	181,75
Greatest breadth at this height to the outside of the plank of the bottom	50,25
Mean depth between the light and load-water-lines .	7,83

$$\text{Then } \frac{3}{4} \cdot \frac{181{,}75 \times 50{,}25 \times 7{,}83}{35} = 1532{,}4 \text{ tons.}$$

The sum of the seven half-breadths to the outside of the ship	161,5
The length of the greatest of these half-breadths .	24,8

$$24{,}8 \times 6 = 148{,}8\text{; then } 161{,}5 - 148{,}8 = 12{,}7.$$

$$12{,}7 \text{ is } 8{,}5 \text{ per cent. of } 148{,}8\text{; and } 1{,}5 \times 8{,}5 = 12{,}75\text{;}$$

$$\text{then } 12{,}75 \text{ per cent. of } 1532{,}4 = 195{,}4 \text{ tons.}$$

Adding 195,4 tons to the first quantity, 1532,4 tons, the result, 1532,4 + 195,4 = 1727,8, the required tonnage.

The light water-line in His Majesty's ships can always be obtained by observation, and in merchant-ships it can be accurately taken when every necessary store is on board, including every thing but the lading, and entered on the register. There would be also frequent opportunities of proving the truth of it. Should this measurement be taken in any case when some of the stores (as anchors, cables, &c.) are not on board, proper deduction must be made for it in the calculation of the tonnage.

The principal trouble in this operation is the measurement of the half-breadths; but it requires only such a degree of attention as every one may be expected to pay who may be directed to perform the operation. The arithmetical operation is very simple, and may be as easily remembered as the present rule.

This rule admits of several modifications: a method less correct, but on the same principle, might be adopted by the measurement of the half-breadths on the lower deck, instead of the half-breadths at the horizontal section at the mean depth between the light and load-water-lines, or the measurement of fewer half-breadths might be taken; but the rule as above stated appears sufficiently easy for practice, particularly as greater correctness is always a sufficient reward for a little more trouble.

Other rules for calculating the tonnage of ships will be given in future numbers of this work.

M.

Art. XXIV.—*On placing the Timbers of the Frame perpendicularly to the Load-Water-Section.*

(*To the Editor of the Papers on Naval Architecture.*)

Sir,—I take the opportunity offered in your periodical work on naval architecture, to mention an observation I lately made in visiting a yard, where I saw several vessels building. I remarked that the bends of timbers were put up perpendicular to the keel, which must cause them, in those vessels which when afloat will draw more water abaft than forward, to incline aft from a perpendicular. This must cause a constant strain on the fastenings, which I consider must much weaken them. In small vessels, particularly, which usually have a much greater difference of draught of water aft and forward than large vessels, this strain must be considerable. One of these vessels was a cutter of about ninety tons, which was to draw five feet more water abaft than forward, which will cause her timbers to incline at an angle of several degrees towards the stern.

I understand that this is the practice for all ships, both in the Royal and private yards. In large ships, which draw but little more water abaft than forward, it can be of little moment; but in cutters it is, I think, at least worthy of consideration, whether it may not be proper to place these timbers as nearly perpendicular to the water-line as can be determined previously to being launched.

Perhaps your insertion of this may lead to further remarks on the subject.[1]

Your obedient Servant,

A. B.

Art. XXV.—*A Translation of the Abbé Bossut's Report on the Experiments on the Resistances of Fluids, which were made by M. D'Alembert, the Marquis De Condorcet, and the Abbé Bossut.*

The investigation of the laws of the action of a fluid in motion against a plane surface, or of the resistance experienced by a solid in moving through a fluid, is perhaps the most important problem of hydrodynamics, whether on account of its difficulty, or of its application to naval architecture, to the construction of dikes, hydraulic machines, &c. Its solution has consequently been attempted by many geometricians. Some have given methods which are easy and simple in the application, but which but very imperfectly represent the reciprocal action and reaction of the fluid and the body. Other methods, more correct in principle, have led to formulas too complicated to be easily reduced to practice. We must therefore, while we admire the skill which has been shown, admit that the subject requires further investigation and research, before any useful results can be deduced.

M. Turgot, the Comptroller-General of Finances, having, in the beginning of the year 1775, directed M. D'Alembert, the Marquis Condorcet, and myself, to examine into the means for perfecting the inland navigation of the kingdom, we considered that the first, and the most important object, would be to endeavour to determine the question of the resistance of fluids. We thought that before applying mathematical investigation, it would be advisable, by means of experiments, either to

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[1] The circumstance mentioned in this letter has been attended to in the construction of the *Sapphire*, of 28 guns, designed by the Rev. Dr. Inman. This ship is now being built in H. M.'s Dockyard at Portsmouth, with the timbers at right angles to the intended load-water-section.—Ed.

establish the truth of the elements of the theories already known, or to procure data to serve as a basis for a new solution. This was more particularly the advice of M. D'Alembert, and was therefore the more conclusive, as that gentleman has solved the question by a new and strictly analytical method, which would leave nothing even to be wished for, could the equations which are deduced be integrated either by converging series, or by any other method.

M. Turgot, who is not only an admirer of the sciences, but has pursued the study of them himself, amidst his numerous important official occupations, approved of our intentions, and granted every requisite for prosecuting them.

This series of experiments was made during the [1] last year, in the months of July, August, and September, on a piece of water in the grounds of the Ecole Militaire, and we were assisted in the execution by most of the professors of that establishment.

The investigation of the laws of nature, by means of experiment, is extremely difficult. It is in vain that facts are collected if they are equivocal, if they are unconnected, or if, being the effects of different causes, there is the smallest doubt in assigning each effect to its immediate cause. Nothing is more common than to hear it observed, that theory, unless completely confirmed by experiment, can be of no practical benefit; that all experiments should be made on the full scale; and that those made on a small scale are useless. But the greater portion of the persons who so confidently repeat these observations, which are in many respects true, would be much embarrassed if it were proposed to them to determine, for any one subject, what experiments would be necessary, or even useful, and on what scale it would be most proper to execute them. These preliminaries, which it is absolutely indispensable should be known, can only be deduced from theoretic examination of the subject.

Nothing can be expected from a man who has nothing but practice without correct principles to guide him, than that he

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[1] The Report was read before the Royal Academy of Sciences on the 7th of April, 1776, and was published in 1777.

will blindly show either the same fact under different appearances, or an assemblage of facts, the differences of which he cannot explain. No science can exist without principles, or, in other words, without a theory.

It is evident, that in the studies of natural philosophy, where the causes of phenomena are endeavoured to be ascertained without the aid of calculation, experiments should be made on as large a scale as possible. But to obtain exact data for the foundation of theories, such experiments lose their advantage; for it is seldom they can be either so exact, so frequently repeated, or so varied, as to clear up the differences and anomalies which may be observed. By this system then, time, trouble, and expense would be incurred in the collection of a very small number of facts, which could be fully relied on. Again, when experiments are conducted on too small a scale, they are dangerous; for facts are liable to be perverted or mistaken, and consequently subsequent analysis cannot be depended upon. But between these extremes, a mean may be chosen, which is, to select such a scale that all the effects shall be decisive and distinct, and that the observations on them may be made with exactness.

Such is the principle which should regulate all experiments which are intended to be submitted to mathematical analysis. I endeavoured to be guided by this rule throughout the experimental part of my hydrodynamics; and it has been the basis of the present series of experiments on the resistance of fluids.

There are, in this subject, two questions to be examined: the one, the resistance of fluids infinite in extent; and the other, the resistance of fluids in bounded spaces. To the first class belong the resistances experienced by vessels at sea, and boats on large and deep rivers; and to the second, those experienced on small rivers and canals, where there is seldom the space required either for a free passage of the craft, or for economizing the moving force.

Very exact and very interesting experiments have, from time to time, been made on the resistances of infinite fluids. The Chevalier de Borda determined the resistance of the air by means of a vane, to the ends of which were attached sails of different extent, which were turned by the action of a weight.

He afterwards employed the same, and other ingenious methods to determine the resistance of water. These experiments are accompanied by some very important remarks on the resistance of fluids.[1] In a very able paper by M. de Marguerite, which is printed among those of the Academie de Marine, it is mentioned that M. Thevenard went through a course of experiments on the resistance of fluids, at l'Orient, and M. Marguerite has taken several of them for the elucidation of his theory.

The examination of the resistances of fluids when in narrow channels may be considered as new, as no experiments have been made for this purpose, if we only except those undertaken by Franklin to satisfy himself as to whether or not boatmen are correct when they say that there is less difficulty in moving a boat when a river is deep than when it is shallow. These experiments, although, as far as they go, they are good, are not nearly sufficient to elucidate the object in view;—in fact, Franklin was satisfied with making a small boat, six inches long, two inches and a quarter broad, and two inches and a quarter deep, pass up and down a channel of five or six inches broad, and fourteen feet long, the depth being varied by means of a shifting bottom. He says, that not having a second-watch to take the correct times employed by the boat in its different passages, he took them by counting from one to ten as fast as possible, and keeping a regular account of the numbers of tens with his fingers; and that, in order to correct any errors which might arise from this imperfect method, he repeated the experiments several times, and took the mean results. He ascertained that the assertion of the boatmen was correct; but that is all which can be drawn from so inadequate an attempt to investigate either the resistance of water in narrow channels, or the relation between this resistance and that which is experienced in fluids infinite in extent.

Our labours embrace the two questions, and we have determined them by parallel means, and on a scale which appears to be the most advantageous; we are therefore able to make the comparisons between them on pure foundations, and without any reference to the labours of those who have preceded us.

[1] See Memoires de l'Academie, year 1763, page 358, and also year 1767, page 495.

We shall begin by a detail of the experiments, and then compare the results with theory.

Chap. 1.—*Preliminary Observations.*

When a fluid which has a uniform motion strikes a body which is at rest,—or when a body moves uniformly in a fluid which is at rest; in either case the impulsion of the fluid against the body is the same. In fact, to reduce the two cases to one, we have only to suppose, in the first, that the fluid is at rest and the body in motion; or, in the second, that the body is at rest and the fluid in motion. Hence all experiments on the resistance of fluids may be reduced to the simple motion, in a fluid which is at rest, of a body of a given figure, by means of a weight or any other motive force, and to the determination of the time employed by the body in passing through a given space.

This is the method which has been pursued in these experiments. Vessels of different forms have been propelled in succession over the fluid, and the times of their motions have been marked, by the use of a pendulum vibrating half-seconds.

The place in which the experiments were made, was a stone-faced basin, about a hundred feet long and fifty-three feet broad, and the greatest depth of water about six feet and a half.

On the wharf, at one end of the basin, a pole, or rather a mast, seventy-six feet high, was erected, having a cross piece at the upper end, in which was a brass sheave, and at the lower end there was a frame-work containing another brass sheave, which was fitted in such a manner that it might be moved either higher or lower, to regulate its height with that of the vessel to be tried. One end of a line being secured to the vessel, it was passed under the lower of the two sheaves and over the upper one; a weight was then fastened to the line, and in order to preserve a constant equilibrium of weight in the cord it was allowed to hang down below the weight, so as always to touch the ground. It has been mentioned, that the lower sheave was moveable, which was that the part of the line between the vessel and the sheave should always be horizontal.

On the wharfs, on each side of the basin, a line was drawn

parallel to the line of motion of the vessels, on each of which lines stations were set off, five feet apart; the stations on either line being opposite to those on the other, so that a line joining any opposite two would be perpendicular to the line of motion of the vessel. During the carrying on of the experiments, persons were placed at these stations to observe the instant when the vessels passed them; to enable them to do which the more correctly, a man called the half-seconds which were marked by the vibrations of a very excellent half-second pendulum.

At the commencement of an experiment, the weight, which is the moving power, is at the top of the mast which has been before mentioned, and the vessel or model is at the further extremity of the basin, that is about sixty-six feet from the goal, if we may so name the line at which the experiment ceases; consequently the model passes through a space of 66 feet. But as at first the motion is very sensibly accelerated, the observations were confined to the last fifty feet, allowing the first sixteen feet to be passed through before any comparison was made between the times and the spaces.

By reference to Fig. 16, the preceding account will be more clearly understood: ABCD is the basin; E the station of the mast, down which the weight which puts the models in motion acts by the force of gravity; F is the model at the commencement of an experiment; $a\,a'$, $b\,b'$, $c\,c'$, &c., are the stations which are placed five feet apart.

The whole of the experiments were repeated several times with the greatest care; and when they only differed slightly, a mean was taken; all those which were not perfectly satisfactory, were again repeated; in those which were kept, the differences of time between two repetitions occupied in passing through the 50 feet, were generally under half a second, and never amounted to a second.

The models are distinguished by numbers. The lower sides of the keels were always parallel to the water-line; and to bring them to this even draught of water, they were loaded as might be necessary with shot or ballast.

As it is almost impossible in practice that the direction of the cord and that of the resultant of the resistances shall remain in the same vertical plane during the vessel's motion, although, if

this is not the case, the vessel will move in a serpentine line, and also oscillate round a vertical axis passing through its centre of gravity, it was endeavoured to prevent these motions, by fixing a rudder at the stern of the vessel. This succeeded very well in a fluid of infinite extent, but had not the same effect in confined channels; another expedient was therefore adopted, which will be described.

The rudder was always made of thin board, the vertical plane of which was fixed in the vertical and longitudinal plane of the vessel; we shall see that the friction this caused was not of any consequence, as the whole friction against the sides, bottom, and rudder, will vanish in comparison to the resistance against the bows. The forms and dimensions of the several models are as follow:—

No. 1 is a right prism, and the base which is horizontal is the pentagon ABCDE having the sides AE, BC, perpendicular to AB, the fore part or bow; the stern being the isosceles triangle CDE. A frame-work of wood, CGFE, wholly out of water, is intended to support the rudder, and keep it in its proper direction.

The breadth AB = [1] 1 foot; the length AE = 4 feet; nD = 2 feet; DH = 4 feet 4 inches; and the depth is 18 inches.

The measurements are all taken from outside to outside.

No. 2 is prismatic in the direction of its depth, and its horizontal section is the hexagon ABCLKE, the sides AE and BC are perpendicular to AB the bow; the stern being the trapezium CLKE. The frame CGFE is to support the rudder DH.

The breadth AB = 2 feet; AE = BC = mn = 4 feet; nD = 2 feet; KL = 1 foot; DH = 4 feet 4 inches; and the depth = 18 inches.

No. 3 is a rectangular parallelopiped, of which AB represents the bow and EC the stern, DH being the rudder supported by an iron rod CFE.

The breadth AB = 19 inches 8 lines; AE, BC, and mD each = 6 feet 1 inch; DH = 5 feet; and the depth = 19 inches 8 lines.

No. 4 is a part of No. 3, cut off by a section perpendicular

[1] The whole of the dimensions and the weights mentioned in this paper are in French measure.

to the length. The length of the part is 2 feet 1 inch and 9 lines.

No. 5 is also a part of No. 3, cut off in the same manner as the last, and 4 feet long.

No. 6 is of a prismatic form, as is represented in perspective by AB (Fig. A). The rectangle CDEF (Fig. B) is a horizontal representation, made at the greatest breadth; (Fig. C) is a vertical longitudinal section, bisecting the body; and (Fig. D) is a transverse vertical section in any part of the body.

The length CD = 6 feet; the breadth = 19 inches 8 lines; and the depth = $19\frac{1}{2}$ inches.

No. 7 is merely No. 1, taking the end which represented the bows in No. 1 to represent the stern in No. 7.

AB = 1 foot, and QT = 2 feet.

Nos. 8, 9, 10, 11, and 12, are similar to No. 2, with the addition of different bows, all being isosceles and the sides vertical, only differing in the lengths DQ.

In No. 8	DQ = 6 inches.
9	12
10	18
11	24
12	30

In the same manner, Nos. 13 and 14 are formed from No. 3.

In No. 13 DQ =	9 inches	$9\frac{1}{2}$ lines.
14	19	8

Nos. 15 and 16 are represented by the longitudinal vertical section KARS; these two are similar to No. 4, with the exception of the bows, which are formed by planes inclined to the surface of the fluid.

In No. 15 KM =	20 inches.
16	39 inches 3 lines.

And in both vessels KA = 19 inches 8 lines.

Nos. 17 and 18 are the preceding two turned upside down.

The thickness MN in these models = 1 inch.

No 19 is No. 3 with a cylindric bow, of which AB is the diameter.

No. 20 is a model from the collection of M. Duhamel; it is represented in perspective by Fig. A; Fig. B is an horizontal section made at the extreme breadth. Fig. C is a longitudinal

vertical section, bisecting the model. Fig. D is the midship section, which corresponds with the lines MN in the plan and profile; and Figs. E and F are sections corresponding with GH in the plan and profile.

The length is 6 feet; the breadth and depth are each 19 inches 8 lines.

Chap. 2.—*On the Resistances of Fluids infinite in extent.*

The water in the basin may be considered as infinite in extent, in relation to the model moving in it. The course described by the model being seventeen feet from the nearest boundary: and as the wake scarcely disturbs the water more than two feet on each side, the remainder may be considered without motion. As there is always more than four feet of water below the bottom of the model, the depth may also be taken as infinite.

When the model is at rest, the fluid is level around it; but as soon as any motion takes place, the water rises by degrees before the bow, and forms a sort of fluid bow, which is above the level of the rest of the water. The height of this bow is greater at the middle than at the sides; in order to distinguish between the two, the one may be called central rising, and the other lateral rising. Sometimes at the extreme angles of the bow the lateral rising is *below* the line of floatation, in which case its value must be negative. These differences have been commonly remarked, but have seldom been observed with sufficientattention. We have only given such results as we can fully depend upon.

The height of the central rising should evidently augment (which it does in fact) as the velocity of the model increases; and as soon as the velocity becomes uniform, the height becomes constant. We have therefore an easy method of ascertaining whether the velocity is uniform, besides the doing so by a comparison of the spaces described in corresponding times.

To avoid confusion, we shall commence the report of the results by giving all those connected with direct resistances;—that is, the resistances against plane surfaces, which strike the fluid in a direction perpendicular to themselves. We shall then proceed to the oblique resistances;—that is, when the surfaces form an oblique angle with the direction of motion.

A Table of the Experiments on Direct Resistances.

Number of the Experiment.	Distinguishing Number of the Vessel.	Draught of Water.	Moving Weight.	Central Rising.	Lateral Rising.	Time occupied in passing through 10 feet.	Time occupied in passing through 50 feet.	Time occupied in passing through 30 feet.	Time occupied in passing through 25 feet.	Time occupied in passing through 10 feet.
		Feet.	Marcs.	Lines.	Lines.	Half Seconds.	Half Seconds.	Half Seconds.	Half Seconds.	Half Seconds.
1	1	1	12	21	15	9,20	17,80		26,62	43,70
2	1	1	14	23	18	8,70	16,70		24,70	40,60
3	1	1	16	26	19	8,12	15,65		23,53	30,37
4	1	1	18			7,40	14,00		20,30	34,30
5	1	1	20	34	26	7,00	13,45		20,25	33,75
6	1	1	22	36	29	7,00	13,50		20,00	32,75
7	1	1	24			6,90	13,00		19,71	32,16
8	2	1	16	18	15	10,57	18,84	25,24	29,00	50,11
9	2	1	20	22	18	9,98	18,96	23,67	27,91	46,83
10	2	1	24	25	21	9,48	18,70	22,95	27,22	44,54
11	2	1	28	27	23	9,00	16,95	21,05	25,13	41,25
12	2	1	32	30	26½	8,10	15,65	19,90	23,58	38,70
13	2	1	36	34		8,00	15,08		22,47	36,66
14	2	1	40	37	30	7,70	14,16		21,02	34,70
15	2	1	44	41	35	7,05	13,55		20,00	33,25
16	2	1	48	44	37	6,91	13,33		19,74	32,33
		Ins. Lin.								
17	3	7 10	10	18		10,87	26,87		31,89	51,94
18	3	7 10	12	18½		10,19	19,64	24,44	29,36	47,75
19	3	7 10	14	21	18	9,50	18,37	22,87	27,25	44,62
20	3	7 10	16	24½		9,06	17,31	21,62	25,43	41,75
21	3	7 10	18	28		8,67	16,00	20,00	23,54	38,84
22	3	7 10	20	32½		8,20	15,80	19,60	23,30	37,80
23	3	7 10	22	35		7,69	15,31	18,71	22,31	36,31
24	3	7 10	24	38		7,31	14,50	18,00	21,28	34,75
25	3	7 10	27	42		6,95	13,50	16,85	20,44	33,40
26	3	7 10	30	46		6,62	13,25	16,62	20,00	32,50
27	3	7 10	36	50		6,35	12,65	15,58	18,58	29,90
28	3	12 5½	10	9		13,97	26,81	33,34	39,37	63,82
29	3	12 5½	12	11		12,60	24,65	30,15	36,20	58,55
30	3	12 5½	14	13		11,60	22,30	27,70	33,00	54,35
31	3	12 5½	16	15		11,00	22,04	27,04	32,28	52,00
32	3	12 5½	18	16½		10,60	20,25	25,25	30,00	48,50
33	3	12 5½	19	17		10,30	19,90	24,70	29,10	47,00
34	3	12 5½	20	18		10,20	19,58	24,07	28,45	46,05
35	3	12 5½	22	19		9,90	18,18	22,81	26,93	44,12
36	3	12 5½	24	20½		9,50	17,36	21,50	25,78	42,07
37	3	12 5½	25	22		9,00	16,94	21,00	24,90	40,70
38	3	12 5½	26	23		8,80	16,85	20,60	24,75	40,25
39	3	12 5½	28	24½		8,21	16,19	19,62	23,65	38,53
40	3	12 5½	30	26		8,06	15,66	19,25	23,06	37,25
41	3	12 5½	32	29		7,80	15,30	19,00	22,40	36,20
42	3	12 5½	35	32½		7,37	14,75	18,06	21,83	35,18
43	3	12 5½	38	34½		7,12	13,96	17,31	20,50	33,50
44	3	15 10	20	15		10,95	21,32	26,25	31,15	50,75
45	3	15 10	24	18		10,00	19,18	24,12	28,43	46,50
46	3	15 10	28	21		9,80	18,31	22,46	26,93	43,31
47	3	15 10	32	24		9,37	17,27	21,37	25,12	41,00

Number of the Experiment.	Distinguishing Number of the Vessel.	Draught of Water.	Moving Weight.	Central Rising.	Lateral Rising.	Time occupied in passing through 10 feet.	Time occupied in passing through 20 feet.	Time occupied in passing through 25 feet.	Time occupied in passing through 30 feet.	Time occupied in passing through 50 feet.
		Feet.	Marcs.	Lines.	Lines.	Half Seconds	Half Seconds.	Half Seconds.	Half Seconds.	Half Seconds.
48	3	15 10	36	27½		8,60	16,56	20,06	24,06	38,75
49	3	15 10	40	33		8,06	15,48	19,18	22,50	36,50
50	3	15 10	44	36		7,70	14,10	18,50	20,99	34,66
51	3	15 10	48	39		7,00	13,80	17,25	20,44	33,69
52	4	12 5½	19			11,05	22,18		32,30	52,15
53	4	12 5½	20	22	16	10,12	19,60		28,45	46,09
54	4	12 5½	24	23	17	9,55	17,45		25,86	42,27
55	4	12 5½	28			8,30	16,30		23,28	38,98
56	6	12 8	8	9		13,91		34,30	40,75	65,75
57	6	12 8	10	12		12,78		30,06	37,38	59,66
58	6	12 8	12	18		11,46		27,66	33,35	54,65
59	6	12 8	14	18		10,38		26,06	30,64	50,80
60	6	12 8	16	22		10,10		24,97	29,11	47,94
61	6	12 8	20	26½		9,33		22,56	26,33	43,14
62	6	12 8	24	30		8,00		19,50	23,69	38,92
63	6	12 8	30	36		7,10		18,78	20,95	34,82
64	6	12 8	36	42		6,96		17,05	20,18	32,72
65	6	12 8	44	50		6,62		15,12	18,69	30,00
66	6	15 11	8	9		16,74		37,67	46,34	74,00
67	6	15 11	10	11		14,31		33,25	40,42	65,56
68	6	15 11	12	13		13,00		31,20	37,20	60,70
69	6	15 11	14	16		12,12		29,36	34,46	56,61
70	6	15 11	16	18		11,10		27,40	32,30	53,05
71	6	15 11	20	22		10,12		24,55	29,25	47,65
72	6	15 11	24	27		9,08		22,43	26,37	43,06
73	6	15 11	30	33		8,31		20,37	24,00	39,25
74	6	15 11	36	38		7,83		18,75	22,08	35,83

On Oblique Resistances.

Number of the Experiment.	Distinguishing Number of the Vessel.	Draught of Water.	Moving Weight.	Central Rising.	Lateral Rising.	Time employed in passing through 10 feet.	Time employed in passing through 20 feet.	Time employed in passing through 25 feet.	Time employed in passing through 30 feet.	Time employed in passing through 50 feet.
		Feet.	Marcs.	Lines.	Lines.	Half Seconds.	Half Seconds.	Half Seconds.	Half Seconds.	Half Seconds.
75	7	1	10	24	0	8,56	15,06		21,18	33,06
76	7	1	12	29	0	7,40	13,95		19,80	30,80
77	7	1	14	33	0	6,80	12,79		18,20	28,70
78	7	1	16	36	0	6,25	11,87		17,25	27,25
79	7	1	18	37	2	5,55	10,85		15,89	25,25
80	7	1	20	38	4	5,25	10,37		15,37	24,50
81	7	1	22	38½		5,00	10,00		14,62	23,62
82	7	1	24	39	6	4,96	9,94		14,50	23,40
83	8	1	12	12	6	12,50	23,75		34,71	55,79
84	8	1	14	14	7	11,20	21,30		31,40	51,40
85	8	1	16	15	7	10,50	20,68		30,70	50,00
86	8	1	20	21	11	8,20	18,20		26,10	43,50
87	8	1	24	27	17	8,16	16,00		23,50	30,50

Number of the Experiment.	Distinguishing Number of the Vessel.	Draught of Water.	Moving Weight.	Central Rising.	Lateral Rising.	Time employed in passing through 10 feet.	Time employed in passing through 20 feet.	Time employed in passing through 25 feet.	Time employed in passing through 30 feet.	Time employed in passing through 50 feet.
		Feet.	Marcs.	Lines.	Lines.	Half Seconds.	Half Seconds.	Half Seconds.	Half Seconds.	Half Seconds.
88	8	1	28	30	19	7,75	14,87		22,50	37,00
89	8	1	32	34	22	7,12	14,00		21,48	34,92
90	8	1	36	39		7,00	13,81		20,37	33,12
91	9	1	12	20		12,00	22,14		31,71	49,71
92	9	1	16	22		9,87	18,75		26,68	42,68
93	9	1	20	24	12	8,68	16,31		23,62	38,18
94	9	1	24	28	11	8,36	15,50		22,50	35,56
95	9	1	28	33	9	7,80	14,45		20,95	32,95
96	9	1	33			7,50	13,60		20,00	31,60
97	10	1	10			12,20	22,10		31,80	49,80
98	10	1	12	14		10,62	19,71		28,21	44,35
99	10	1	14			9,87	17,80		26,00	41,00
100	10	1	16	22		9,30	17,30		25,00	39,00
101	10	1	20	24	11	8,25	15,75		22,69	35,75
102	10	1	24	27		8,00	14,50		20,64	32,62
103	10	1	28	33		7,46	13,39		19,37	30,37
104	10	1	32	38		7,00	12,87		18,57	28,87
105	11	1	10	16		11,62	21,56		29,76	45,62
106	11	1	12	18		9,83	18,46		26,16	41,50
107	11	1	12	21		9,75	18,00		25,56	39,96
108	11	1	16	24	6	9,55	16,88		23,90	37,70
109	11	1	20	29	0	9,30	15,10		21,50	33,45
110	11	1	24	35	0	8,00	13,60		19,40	30,70
111	11	1	28	40		7,20	12,90		18,20	28,50
112	11	1	32	45		6,90	12,70		17,60	27,60
113	12	1	10	16		12,35	21,00		29,70	45,50
114	12	1	12	21	4	11,12	18,50		26,62	41,12
115	12	1	14	24	0	10,32	18,40		25,80	39,40
116	12	1	16	29	4	9,85	16,87		23,75	36,62
117	12	1	20	33	6	8,65	15,00		21,20	33,40
118	12	1	24	38		7,70	14,10		19,68	30,81
119	12	1	28	45		7,17	13,20		18,37	28,62
120	12	1	32	52		6,88	12,34		17,40	27,00
		Ins. Lin.								
121	13	7 10	10	17		9,35	17,25	21,70	26,00	41,60
122	13	7 10	12	23		8,06	16,25	20,44	23,81	38,18
123	13	7 10	14	28	10	7,75	15,06	18,81	21,80	35,37
124	13	7 10	16	30	12	7,40	14,80	18,35	21,30	33,90
125	13	7 10	18	35		6,90	13,40	16,81	19,70	31,95
126	13	7 10	20	39		6,80	13,10	16,40	18,90	30,45
127	13	12 5½	10	13	2	11,85	22,60	27,05	33,10	52,00
128	13	12 5½	12	16	2	11,40	21,30	25,05	30,50	47,90
129	13	12 5½	14	20	3	10,71	20,00	23,12	28,70	45,12
130	13	12 5½	16	24	5	10,00	18,53	21,75	26,52	42,06
131	13	12 5½	18	26	7	9,50	17,67	20,68	25,10	39,87
132	13	12 5½	20	30	8	9,00	16,31	10,01	23,57	37,68
133	13	12 5½	22	34	9	8,31	15,50	18,42	22,00	35,50
134	13	12 5½	24	36	10	8,20	15,25	18,30	21,97	34,90
135	13	12 5½	26	38		7,96	14,56	17,75	21,60	34,00
136	13	12 5½	28	39½		7,38	13,81	16,87	20,45	32,37
137	13	12 5½	30	41		7,18	13,40	16,50	19,59	31,05
138	13	15 10	10	8	2	13,83	25,75	31,25	37,25	59,15
139	13	15 10	12	11		13,00	24,10	29,05	34,55	54,60
140	13	15 10	14	14	0	12,41	22,74	27,37	32,23	51,11

Number of the Experiment.	Distinguishing Number of the Vessel.	Draught of Water.	Moving Weight.	Central Rising.	Lateral Rising.	Time employed in passing through 10 feet.	Time employed in passing through 20 feet.	Time employed in passing through 25 feet.	Time employed in passing through 30 feet.	Time employed in passing through 50 feet.
		Feet.	Marcs.	Lines.	Lines.	Half Seconds.	Half Seconds.	Half Seconds.	Half Seconds.	Half Seconds.
141	13	15 10	16	10½	0	11,12	20,55	25,31	20,32	47,20
142	13	15 10	18	17		10,00	19,94	23,65	27,52	44,15
143	13	15 10	20	18½		9,45	17,57	22,65	25,82	42,00
144	13	15 10	22	20		9,00	17,00	21,61	24,82	40,25
145	13	15 10	24	23		8,67	16,31	20,65	23,67	38,40
146	14	7 10	10	20	0	8,62	16,25	20,15	23,57	36,57
147	14	7 10	12	26		8,30	14,81	18,47	22,00	34,00
148	14	7 10	14	32		8,00	14,60	17,50	20,92	32,12
149	14	7 10	16	36		7,80	13,80	16,25	19,81	30,41
150	14	7 10	18	40		7,40	13,29	15,65	19,05	29,20
151	14	7 10	20	44		7,00	12,79	15,10	18,26	28,10
152	14	7 10	22	47		6,60	12,20	14,60	17,32	27,00
153	14	7 10	24	50		6,25	11,85	14,40	16,69	26,25
154	14	12 5½	10	15	2	11,81	21,60	25,54	30,46	47,18
155	14	12 5½	12	18	2	11,00	19,80	23,12	27,50	42,85
156	14	12 5½	14	20		10,09	17,84	22,00	25,00	39,45
157	14	12 5½	16	24		9,30	16,90	20,10	23,60	37,15
158	14	12 5½	18	29		9,00	15,90	19,00	22,78	35,50
159	14	12 5½	20	35		8,40	15,00	18,05	22,02	34,00
160	14	12 5½	24	40		7,80	14,00	16,70	19,81	31,10
161	14	12 5½	28	45		7,00	13,04	16,15	18,61	29,30
162	14	12 5½	30	50		6,50	12,20	15,15	17,44	27,55
163	14	15 10	10	11	3	12,98	23,76	27,66	33,62	51,15
164	14	15 10	12			11,90	21,75	25,31	30,47	46,87
165	14	15 10	14			10,85	20,10	24,00	28,50	44,00
166	14	15 10	16	18	5	10,20	19,00		26,85	41,50
167	14	15 10	18	24		10,00	18,12		25,27	39,12
168	14	15 10	20	30		9,70	16,62		23,82	36,94
169	15	12 5½	16			9,08	17,21		25,22	41,00
170	15	12 5½	20	18	12	8,00	15,33		23,08	37,50
171	15	12 5½	24	24	18	6,90	14,00		20,00	33,32
172	15	12 5½	28	30	24	6,00	15,50		18,84	31,20
173	16	12 5½	12			9,22	17,55		25,25	40,33
174	16	12 5½	16			8,22	15,60		22,50	35,95
175	16	12 5½	20	18	12	7,22	13,92		20,10	32,15
176	16	12 5½	24			6,25	12,37		18,05	29,00
177	17	12 5½	12	18	12	13,10	26,15		39,20	65,00
178	17	12 5½	16	24	18	11,10	23,13		34,63	57,50
179	17	12 5½	20			9,20	19,90		30,13	51,00
180	17	12 5½	24			7,60	17,12		27,83	46,80
181	18	12 5½	12	19	13	11,60	24,00		35,50	59,00
182	18	12 5½	16	24	18	9,20	20,15		31,50	52,40
183	18	12 5½	20	30	24	9,00	19,10		28,60	47,50
184	18	12 5½	24	36	30	8,80	18,72		27,79	44,89

On Resistances on Curved Surfaces.

Number of the Experiment.	Distinguishing Number of the Vessel.	Draught of Water.	Moving Weight.	Central Rising.	Time employed in passing through 10 feet.	Time employed in passing through 20 feet.	Time employed in passing through 25 feet.	Time employed in passing through 30 feet.	Time employed in passing through 50 feet.
		Ins. Lin.	Marcs.	Lines.	Half Seconds.	Half Seconds.	Half Seconds.	Half Seconds.	Half Seconds.
185	19	7 10	12	26	8,06	16,07		22,75	36,00
186	19	7 10	16	33	7,40	13,75		30,20	32,20
187	19	7 10	20	40	6,92	12,68		18,76	29,60
188	19	7 10	24	46	6,28	11,83		17,33	27,40
189	19	12 5½	12	29	10,00	19,10		28,00	44,00
190	19	12 5½	16	26	9,12	17,18		24,37	38,50
191	19	12 5½	20	32	8,70	16,05		22,60	35,40
192	19	12 5½	24	38	8,10	14,31		21,12	32,69
193	19	15 10	12	15	11,31	21,75		31,12	49,31
194	19	15 10	16	20	9,20	18,00		26,32	42,62
195	20	12 8	6	24	9,10		20,55		35,70
196	20	12 8	8	30	7,87		18,00		31,81
197	20	12 8	10	38	7,40		15,45		27,90
198	20	12 8	12	48	6,25		14,56		26,50
199	20	15 11	8	33	9,94		20,71		36,69
200	20	15 11	10	36½	7,82		17,89		32,50
201	20	15 11	12	40	7,00		17,00		30,75

Chap. 3.—*On the Resistance of Fluids when in narrow Channels.*

In the same basin which was used for the preceding experiments, a horizontal flooring was laid at a given depth, about 75 feet long and 11 feet broad. On this flooring were erected two vertical frames, which were so constructed that they might be moved nearer to, or farther from each other, always with a parallel motion.

When the channel was very narrow it was found impossible to keep the vessel's line of motion straight, even with the assistance of the rudder. A cord was therefore stretched tightly along the middle of the channel, and the vessel was kept in its proper course by it by means of two pulleys, or small rollers, which were fixed at the stem, and two at the stern, which the cord passed between without any visible friction.

In most of the experiments which follow, the channel was open at both ends, to allow a free passage to the fluid which was before the vessel, and to allow that which was behind to follow it. But we have also made some experiments with the

channel closed at both ends, that the results of this hypothesis might be compared with those of the first.

By the depth of the channel is meant the height of the water above the flooring. This height was varied by letting more water into the basin.

Direct Resistances,

The Channel being open at both ends.

Number of the Experiment.	Depth of the Channel	Breadth of the Channel.	Distinguishing Number of the Vessel.	Draught of Water.	Moving Weight.	Central Rising.	Lateral Rising.	Time employed in passing through 10 feet.	Time employed in passing through 20 feet.	Time employed in passing through 30 feet.	Time employed in passing through 50 feet.
	Ins. Lin.	Inches.		Feet.	Marcs.	Lines.	Lines.	Half Seconds.	Half Seconds.	Half Seconds.	Half Seconds.
1	15 2	28½	1	1	16	22	12	11,04	21,61	31,82	50,86
2	15 2	28½	1	1	20	26	21	10,80	20,35	29,70	46,95
		Ins. Lin.									
3	15 2	28 6	1	1	24	30	24	9,85	17,90	26,35	42,30
4	15 2	28 6	1	1	28	35	30	9,00	17,20	25,20	39,80
5	15 2	28 6	1	1	32	40	34	8,30	16,50	24,25	38,65
6	15 2	28 6	2	1	32	18		17,08	31,96	45,58	68,83
7	15 2	28 6	2	1	40	24	18	15,75	29,41	41,50	62,75
8	15 2	28 6	2	1	48	30	24	15,33	27,66	39,41	59,33
9	15 2	28 6	2	1	56	34	26	13,70	15,50	36,30	54,80
				Ins. Lin.							
10	15 2	28 6	4	12 5½	24	18	12	17,14	32,75	45,96	69,86
11	15 2	28 6	4	12 5½	32	24	18	15,05	28,40	40,60	61,80
12	15 2	28 6	4	12 5½	40	30	21	13,65	25,45	36,50	55,65
13	15 2	28 6	4	12 5½	48	36	24	13,00	24,50	35,00	52,50
14	15 2	28 6	5	12 5½	24	18	12	16,62	31,46	44,94	68,79
15	15 2	28 6	5	12 5½	32	22	16	15,00	27,90	40,25	61,40
16	15 2	28 6	5	12 5½	40	26	20	13,04	25,29	35,63	54,29
17	15 2	28 6	5	12 5½	48	30	24	11,65	22,95	32,70	49,85
18	15 2	28 6	6	12 8	24	15	9	14,55	27,65	39,95	61,30
19	15 2	28 6	6	12 8	32	18	12	12,80	24,25	34,65	53,45
20	15 2	28 6	6	12 8	40	24	18	11,05	21,00	30,55	47,45
21	15 2	28 6	6	12 8	48			10,15	19,95	28,75	44,31
				Feet.							
22	15 2	40 0	1	1	16	24	18	9,70	18,80	27,90	45,10
23	15 2	40 0	1	1	20	30	24	8,60	16,85	25,25	41,00
24	15 2	40 0	1	1	24	36	24	8,40	16,05	24,10	38,50
25	15 2	40 0	1	1	32	48	40	7,37	14,30	21,71	34,81
26	15 2	40 0	2	1	32	24	20	13,85	26,70	38,30	60,10
27	15 2	40 0	2	1	40	30	24	40,25	24,05	35,05	54,75
28	15 2	40 0	2	1	48	36	28	11,90	22,65	32,90	51,00
				Ins. Lin.							
29	15 2	40 0	5	12 5½	24	24	18	14,75	28,00	40,75	63,37
30	15 2	40 0	5	12 5½	32	29	21	12,30	23,80	34,75	54,60
31	15 2	40 0	5	12 5½	40	34	24	11,50	21,87	31,82	49,62
32	15 2	40 0	5	12 5½	48	38	30	10,25	20,35	29,95	46,25
33	15 2	40 0	6	12 8	24	24	20	12,16	22,48	33,19	53,00
34	15 2	40 0	6	12 8	32	30	24	9,79	19,59	28,76	46,00
35	15 2	40 0	6	12 8	40	36	30	9,00	18,00	26,15	42,00

Number of the Experiment.	Depth of the Channel.	Breadth of the Channel.	Distinguishing Number of the Vessel.	Draught of Water.	Moving Weight.	Central Rising.	Lateral Rising.	Time employed in passing through 10 feet.	Time employed in passing through 20 feet.	Time employed in passing through 30 feet.	Time employed in passing through 50 feet.
	Ins. Lin.	Ins. Lin.		Feet	Marcs.	Lines.	Lines.	Half Seconds.	Half Seconds.	Half Seconds.	Half Seconds.
36	15 6	75 0	1	1	16	24	20	8,58	17,00	24,75	40,00
37	15 6	75 0	1	1	20	28	23	7,50	14,10	21,25	35,00
38	15 6	75 0	1	1	24	32	26	6,40	13,00	20,00	33,00
39	15 6	75 0	2	1	32	30	24	10,42	20,00	29,83	47,83
40	15 6	75 0	2	1	40	38	30	9,60	18,70	27,40	44,00
41	15 6	75 0	2	1	48			8,85	16,85	25,25	40,55
				Ins.Lin.							
42	15 6	75 0	5	12 5½	24	26	22	10,00	21,00	31,00	51,07
43	15 6	75 0	5	12 5½	32	34		9,50	20,00	28,60	46,10
44	15 6	75 0	5	12 5½	40	39	32	8,79	17,67	27,00	43,00
45	15 6	75 0	5	12 5½	48	48	40	8,15	17,04	25,00	40,00
46	15 6	75 0	6	12 8	24	24	20	9,75	19,00	27,90	45,60
47	15 6	75 0	6	12 8	32	34	28	8,55	16,60	24,60	40,10
48	15 6	75 0	6	12 8	40	44	34	7,70	15,10	22,20	36,10
				Feet.							
49	15 4	Indefi.	2	1	32	36	30	9,00	17,00	25,25	41,66
50	15 4		2	1	40	42	34	7,87	15,00	22,76	37,56
51	15 4		2	1	48	48		7,00	14,37	21,62	35,37
				Ins.Lin.							
52	15 4		5	12 5½	32	36	30	9,25	17,37	25,56	41,50
53	15 4		5	12 5½	40	42	36	7,87	15,20	22,50	37,00
54	15 4		5	12 5½	48	48	42	7,31	14,87	21,87	35,25
				Feet.							
55	27 3		2	1	32	30	24	8,10	16,45	24,65	40,65
56	27 3		2	1	40	39	33	7,50	13,90	21,10	35,60
57	27 3		2	1	48	36	38	6,80	12,80	19,05	32,55
				Ins.Lin.							
58	27 3		5	12 12½	32	30	18	8,50	16,25	23,87	39,00
59	27 3		5	12 12½	40	36	24	7,37	14,56	21,55	35,15
60	27 3		5	12 12½	48	42	32	6,46	12,52	19,25	31,83

Oblique Resistances.

Number of the Experiment.	Depth of the Channel.	Breadth of the Channel.	Distinguishing Number of the Vessel.	Draught of Water.	Moving Weight.	Central Rising.	Lateral Rising.	Time employed in passing through 10 feet.	Time employed in passing through 20 feet.	Time employed in passing through 30 feet.	Time employed in passing through 50 feet.
	Ins.Lin.	Ins. in.		Feet.	Marcs.	Lines.	Lines.	Half Seconds.	Half Seconds.	Half Seconds.	Half Seconds.
61	15 ½	28 ½	7	1	16	14		8,90	18,10	26,40	42,80
62	15 ½	28 ½	7	1	20	18		8,10	16,28	24,12	39,37
63	15 ½	28 ½	7	1	25	24		7,40	15,32	22,80	37,25
64	15 ⅓	28 ½	9	1	32	18	12	16,12	29,52	41,87	64,83
65	15 ⅓	28 ½	9	1	40	24	18	14,87	26,87	38,47	59,60
66	15 ⅓	28 ½	9	1	48	30	24	13,30	24,50	35,40	54,50

Direct Resistances,

The Channel being closed at each end.

Number of the Experiment.	Depth of the Channel.	Breadth of the Channel.	Distinguishing Number of the Vessel.	Draught of Water.	Moving Weight.	Central Rising.	Lateral Rising.	Time employed in passing through 10 feet.	Time employed in passing through 20 feet.	Time employed in passing through 30 feet.	Time employed in passing through 50 feet.
	Ins. Lin.	Ins. Lin.		Feet.	Marcs.	Lines.	Lines.	Half Seconds.	Half Seconds.	Half Seconds.	Half Seconds.
67	15 ½	28 ½	1	1	16	24	18	10,00	20,25	30,00	49,00
68	15 ½	28 ½	1	1	20	30	24	9,00	18,87	27,87	45,12
69	15 ½	28 ½	1	1	24	36	30	8,80	17,50	25,81	41,94
70	15 ½	28 ½	2	1	32	18	12	27,40	30,00	43,40	69,80
71	15 ½	28 ½	2	1	40	24	18	14,10	27,11	39,80	64,20
72	15 ½	28 ½	2	1	48	30	24	13,60	25,80	37,65	60,60

In the experiments on indefinite fluids, which are the subject of the preceding chapter, the vessels were kept in a straight course by means of rudders; in those detailed in this chapter, a cord running between rollers was used. It remains to consider, whether the resistances occasioned by these two means are the same. The three following experiments have been made on this account, in which the vessels were directed by rudders, and they may be compared with the experiments 39, 40, and 41. By these comparisons it will be seen that the resistance occasioned by the rollers is greater than that occasioned by the rudders; the difference is, however, so small that it may be neglected.

Number of the Experiment.	Depth of the Channel.	Breadth of the Channel	Distinguishing No. of the Vessel.	Draught of Water.	Moving Weight.	Time employed in passing through 10 Feet.	Time employed in passing through 20 Feet.	Time employed in passing through 30 Feet.	Time employed in passing through 50 Feet.
	In. L.	Inches		Feet.	Marcs.	Half Seconds.	Half Seconds.	Half Seconds.	Half Seconds.
73	15½	75	2	1	32	10,00	19,96	29,25	47,15
74	15½	75	2	1	40	9,35	18,25	27,05	43,80
75	15½	75	2	1	48	8,65	16,70	25,15	40,45

Chap. 4.—*Remarks and Experiments, in addition to those in the preceding Chapter.*

THE experiments which occasion this addition are those which, having appeared to be less correct than the others, were intended to have been suppressed. But notwithstanding several irregularities in the motions, which we shall explain, they follow the same law which seems to exist among the others; we have therefore given them as a supplement. They possess the advantage of showing, at least very nearly, the resistances experienced by bows of very large superficies.

No. 21 is the No. 5, moved in such a manner that the side, which is four feet wide, serves as a bow. No. 22 is only No. 21, with a triangular bow fitted to it, the height of which DQ = one foot.

These vessels moved in a serpentine line, in spite of the rudder or the cord. This, of course, diminished the velocity; consequently, if we had taken the times of the whole passage, we should have taken too much: we have therefore only taken the times for the last twenty feet, which may be considered as having been described as nearly uniform.

In the first fourteen experiments which follow, the vessel is directed by a rudder, and the fluid is indefinite in every direction. In the three others the vessel is directed by the cord; the fluid is only indefinite in breadth; and the flooring, which has been already mentioned, was 27 inches 3 lines below the surface.

Number of the Experiment.	Distinguishing No. of the Vessel.	Draught of Water.	Moving Weight.	Central Rising.	Lateral Rising.	Time employed in passing through 20 Feet.	Time employed in passing through 30 Feet.	Time employed in passing through 50 Feet.
		Ins. Lin.	Marcs.	Lines.	Lines.	Half Secs.	Half Secs.	Half Secs.
1	21	12 5½	16	2		37,45	55,00	91,00
2	21	12 5½	20	5		34,25	50,50	83,00
3	21	12 5½	30	7		28,00	42,50	69,00
4	21	12 5½	40	11		25,00	37,00	60,50
5	21	12 5½	50	15		22,50	54,00	55,00
6	21	12 5½	60	20		21,00	30,55	50,00
7	21	12 5½	70	23		20,00	26,00	46,00
8	22	12 5½	16	3		32,00	50,00	80,00
9	22	12 5½	24	7	3	26,00	39,90	65,40
10	22	12 5½	32	12	6	23,40	34,70	57,00
11	22	12 5½	40	18		22,00	31,00	51,00
12	22	12 5½	48	22		19,25	29,35	47,50
13	22	12 5½	56	25		18,10	28,45	45,00
14	22	12 5½	64	28		16,15	27,10	42,65
15	21	12 5½	32	6		28,50	41,00	67,00
16	21	12 5½	40	12		25,50	37,15	61,00
17	21	12 5½	48	18		23,50	33,52	55,52

Chap. 5.—*A Comparison of the usual Theory of the Resistances of Infinite Fluids, with the foregoing Experiments.*

Every theory which is to be practically applied, should be simple in its principles. This is the character of that which has been hitherto given of the resistance of indefinite fluids, and which has been applied by the Bernoullis, Euler, Bouguer, &c., in many excellent works. It may now, by being put to the test of a comparison with experiment, be ascertained either to be correct, to require alteration, or to be entirely exploded.

According to this theory, any body moving in a fluid with different velocities experiences resistances which are proportional to the squares of the velocities; if several planes act perpendicularly against a fluid with the same velocity, they experience resistances proportional to their surfaces; a plane which, being moved parallel to itself, with a constant velocity, strikes the fluid successively under different angles, experiences in a perpendicular direction a resistance which varies as the square of the sine of the angle of incidence of the fluid against the plane.

Under these general relations, the resistances experienced

by plane surfaces may be compared in every possible case; and also the resistances on curved surfaces, if we consider the elementary parts of such surfaces as planes, and take the sum of the impulses on them.

With regard to the absolute measure of the resistance, there are differences in the opinions of authors. Some affirm that the perpendicular resistance of a plane surface is equal to the weight of a column of fluid having the plane surface for a base, and for its height, the height due to the velocity with which it is struck. Others affirm that the resistance is the double of the same column.

Very legitimate doubts are held as to the exactness of this theory; for it supposes that each particle of fluid strikes the plane as if it were an independent and isolated body,—a supposition which is contrary to nature. In fact, each lamina of fluid which comes in contact with the plane is followed by a second, and that by a third, &c. Now as the first cannot either be totally destroyed or instantaneously removed by the sides, it must hinder and alter the action of the second, and that in the same manner will impede the effect of the third, &c.

Thus the column of fluid supported by the plane must accumulate in every direction, and the resistance it opposes cannot be the same as if each lamina were destroyed immediately after the contact with the plane, to allow a full and free action to the succeeding one. It appears evident, therefore, that it is erroneous to calculate the resistance as if the plane received simultaneously and with full intensity, the impact of each of the particles of fluid which must successively come in contact with it. But may it not also be the case, that the resistances on different surfaces are equally liable to a change, and that the actual resistances may bear to each other the same law, or nearly so, as the theoretic. This perhaps may be deduced from experiment.

The question under consideration embraces several branches, which must each form the subject of discussion.

Section 1.—*Whether the Resistances experienced by the same Surface, when moved with different Velocities, vary as the Squares of the Velocities.*

The weight, which in these experiments is the moving power, descends, by its gravity, from a state of rest, and puts in motion the whole mass of the model, including the ballast and that of the cord, overcomes the friction, the resistance of the water, and that of the air against the part of the model which is not immersed. At first the motion is accelerated; and as long as the acceleration continues, the moving weight has not only to overcome the resistances of the water and the air, but the inertia of the model and cord. The motion soon becomes uniform, and then the moving weight has only to act against the friction, and the resistances of the water and air: for the motion communicated to the model and cord will maintain itself, and therefore those two things need only be considered when referring to the acceleration of the motion; and when it becomes uniform they can no longer be considered as forming a part of the moving weight.

If it is wished to make these experiments the foundation for calculations on the acceleration of motion, all the necessary data are given. For the weight of the mass of the model is equal to that of the water it displaces; and this may easily be found from the dimensions of each model, and the depth it sinks in the water. The cord weighs 28 ounces 7½ grains for every 39½ toises; but this weight was taken before the cord was stretched; it was estimated, after stretching, that the cord, from the moving weight to the model, which was 152 feet in length, weighed 12 or 13 ounces. The friction, the resistance of the water, and that of the air, may be determined by any one of the theories which may be considered the most correct.

The results which are deduced may be compared with experiment, as care has been taken to commence reckoning the times and spaces before the acceleration had ceased, and also the model has already passed through 16 feet before, in our tables, it is supposed to have commenced motion.

We content ourselves with mentioning these calculations, which are only objects of curiosity. The question which occu-

pies our attention is, to determine the resistance of the water when the motion of the model is uniform, which it certainly may be considered to be for the last thirty feet of the space described, or at least if there be any acceleration, it is so small as to be undeterminable by experiments in which other circumstances, such as friction and the resistance of the air, may produce effects which might be mistaken for it. Thus we cannot be in error if we only consider the motion as being uniform for the last twenty feet of space.

In the last seven experiments, made with the model, number 20, the motion is considered uniform for the last twenty-five feet. It is true, that if we compare the time of describing this space with that of describing the first twenty-five, it will be found that the former is shorter than the latter; from which it may be inferred, that there is still an acceleration of motion in describing the last twenty-five feet. But in these experiments the moving power, or weight, is so small that it allows the cord to form a bag downwards, which is detrimental to the uniformity of the motion; and this bag is of course more considerable in proportion as the moving weight is small, or the length of cord great; and it will diminish as these reasons for its existence diminish, and is therefore very small during the last twenty-five feet; which may consequently be supposed to be described with an uniform motion, or so nearly so, that the correctness of the deductions made with that hypothesis shall be ensured.

At the commencement of any motion, it is generally considered that the friction is very nearly in proportion to the pressure. We have established the truth of this law, and we shall give the experiments which were made on that account, when we come to consider of the absolute value of the resistance of a surface. The same law should certainly be observed in comparing together uniform motions, at least if there be no great difference in the velocities. For if on the one hand there is a greater number of particles in contact, in consequence of the increase of velocity, on the other hand the increase of velocity allows less time for the points and cavities of the surfaces in contact to adjust themselves to each other; there is therefore a sort of equilibrium between the causes which tend to increase the friction, and those which tend to diminish it. We will

therefore suppose that the motion being considered uniform, the friction is proportional to the pressure. Then the moving weights, minus the effects of the friction, are to each other as the weights before that deduction is made, since we have the proportion

$$P - \frac{P}{m} : P' - \frac{P'}{m} :: P : P'$$

The constant quantity, m, represents the relation between the pressure and the friction, and P or P′ is the absolute pressure.

We neglect the resistance of the air, as being infinitely small in comparison with that of the water; but it will be taken into consideration when we wish to get the actual value of the resistance of the water.

There is also friction along the sides and the bottom of the vessel, which we shall also see is so small that it may be neglected.

The two following tables have been calculated with reference to all these observations. In each of them the first column is the number of the model; the second that of the experiment; the third contains the times, expressed in half-seconds, employed in describing the last twenty or twenty-five feet; the fourth column shows the weights, in marcs, which represent the relations of the resistances according to theory; so that for each model there is a weight which is given by experiment, and which serves as a basis on which to determine others, in the hypothesis that the resistances are as the squares of the velocities; and lastly, the fifth column shows the weights which express the true relations between the resistances, as determined by experiment.

TABLE I.

Section 2.—*Relation between the Resistances experienced by a Surface moving with different Velocities in an Infinite Fluid, according to the Theory and to the Experiments.*

Number of the Vessel.	Number of the Experiment.	Time of passing through the last 20 Feet.	Weight calculated by the Theory.	Weight shown by the Experiments.
		Half Seconds.	Marcs.	Marcs.
No. 1.	1	17,08	12 .. base	12
	2	15,90	13,84	14
	3	14,84	15,89	16
	4	14,00	17,86	18
	5	13,50	19,21	20
	6	12,75	21,53	22
	7	12,45	22,58	24
No. 2.	8	21,11	16,16	16
	9	18,92	20,11	20
	10	17,32	24 .. base	24
	11	16,12	27,70	28
	12	15,12	31,49	32
	13	14,19	35,75	36
	14	13,68	38,47	40
	15	13.25	41,01	44
	16	12,59	45,42	48
No. 3. First Draught of Water.	17	20,05	10,10	10
	18	18,39	12 .. base	12
	19	17,37	13,45	14
	20	16,32	15,24	16
	21	15,30	17,34	18
	22	14,50	19,30	20
	23	14,00	20,71	22
	24	13,47	22,37	24
	25	12,96	24,16	27
	26	12,50	25,97	30
	27	11,32	31,67	36
No. 3. Second Draught of Water.	28	24,45	10,03	10
	29	22,35	12 .. base	12
	30	21,35	13,15	14
	31	19,72	15,41	16
	32	18,50	17,51	18
	33	17,90	18,71	19
	34	17,60	19,35	20
	35	17,19	20,28	22
	36	16,29	22,59	24
	37	15,80	24,01	25
	38	15,50	24,95	26
	39	14,88	27,07	28
	40	14,19	29,77	30
	41	13,80	31,48	32
	42	13,35	33,63	35
	43	13,00	35,47	38

Number of the Vessel.	Number of the Experiment.	Time of passing through the last 20 Feet.	Weight calculated by the Theory.	Weight shown by the Experiments.
		Half Seconds.	Marcs.	Marcs.
No. 3. Third Draught of Water.	44	19,60	20 .. base	20
	45	18,07	23,53	24
	46	16,88	26,96	28
	47	15,88	30,47	32
	48	14,69	35,60	36
	49	14,00	39,20	40
	50	13,67	41,13	44
	51	13,25	43,77	48
No. 4.	52	19,85	16 .. base	16
	53	17,84	19,81	20
	54	16,41	23,41	24
	55	15,70	25.58	28
No. 6. First Draught of Water.	56	25,00	8,71	8
	57	22,28	10,97	10
	58	21,30	12.. base	12
	59	20,16	13,40	14
	60	18,83	15,35	16
	61	16,81	19,27	20
	62	15,23	23,47	24
	63	13,87	28,30	30
	64	12,54	34,62	36
	65	11,31	42,56	44
No. 6. Second Draught of Water.	66	27,66	8,66	8
	67	25,14	10,49	10
	68	23,50	12 .. base	12
	69	22,15	13,51	14
	70	20,75	15,39	16
	71	18,42	19,53	20
	72	16,69	23,79	24
	73	15,25	28,49	30
	74	13,75	35,05	36
No. 7.	75	11,88	10,29	10
	76	11,00	12 .. base	12
	77	10,50	13,17	14
	78	10,00	14,52	16
	79	9,36	16,57	18
	80	9,13	17,42	20
	81	9,00	17,93	22
	82	8,90	18,33	24
No. 8.	83	21,08	12 .. base	12
	84	20,00	13,33	14
	85	19,30	14,32	16
	86	17,40	17,61	20
	87	15,00	23,70	24
	88	14,50	25,36	28
	8	13,44	29,52	32
	90	12,75	32,80	36

Number of the Vessel.	Number of the Experiment.	Time of passing through the last 20 Feet.	Weight calculated by the Theory.	Weight shown by the Experiments.
		Half Seconds.	Marcs.	Marcs.
No. 9.	91	18,00	12.. base	12
	92	16,00	15,19	16
	93	14,56	18,34	20
	94	13,06	22,79	24
	95	12,00	27,00	28
	96	11,60	20,89	32
No. 10.	97	18,00	9,65	10
	98	16,14	12.. base	12
	99	15,00	13,89	14
	100	14,00	15,95	16
	101	13,06	18,33	20
	102	11,98	24,78	24
	103	11,00	25,83	28
	104	10,30	29,47	32
No. 11.	105	15,86	11,22	10
	106	15,34	12.. base	12
	107	14,40	13,62	14
	108	13,80	14,83	16
	109	11,95	19,77	20
	110	11,30	22,11	24
	111	10,30	26,61	28
	112	10,00	28,24	32
No. 12.	113	15,80	10,11	10
	114	14,50	12.. base	12
	115	13,60	13,64	14
	116	12,87	15,23	16
	117	12,20	16,95	20
	118	11,13	20,37	24
	119	10,25	24,01	28
	120	9,60	27,37	32
No. 13. First Draught of Water.	121	15,60	10,18	10
	122	14,37	12.. base	12
	123	13,57	13,45	14
	124	12,60	15,61	16
	125	12,25	16,51	18
	126	11,55	18,57	20
	127	18,90	10,17	10
	128	17,40	12.. base	12
	129	16,42	13,16	14
No. 13. Second Draught of Water.	130	15,54	13,19	16
	131	14,77	16,65	18
	132	14,10	18,27	20
	133	13,50	19,94	22
	134	12,93	21,73	24
	135	12,40	23,63	26
	136	11,92	25,57	28
	137	11,46	27,66	30

Number of the Vessel.	Number of the Experiment.	Time of passing through the last 20 feet.	Weight calculated by the Theory.	Weight shown by the Experiment.
		Half Seconds.	Marcs.	Marcs.
No. 13. Third Draught of Water.	138	21,90	10,06	10
	139	20,05	12 .. base	12
	140	18,88	13,53	14
	141	17,88	15,09	16
	142	16,98	16,73	18
	143	16,18	18,43	20
	144	15,43	20,26	22
	145	14,73	22,24	24
No. 14. First Draught of Water.	146	13,00	10,22	10
	147	12,00	12 .. base	12
	148	11,20	13,77	14
	149	10,60	15,38	16
	150	10,15	16,77	18
	151	9,84	17,85	20
	152	9,68	18,44	22
	153	9,56	18,91	24
No. 14. Second Draught of Water.	154	16,72	10,11	10
	155	15,35	12 .. base	12
	156	14,45	13,54	14
	157	13,55	15,40	16
	158	12,72	17,47	18
	159	11,98	19,70	20
	160	11,29	22,18	24
	161	10,69	24,74	28
	162	10,11	27,66	30
No. 14. Third Draught of Water.	163	17,88	10,10	10
	164	16,40	12 .. base	12
	165	15,50	13,43	14
	166	14,65	15,04	16
	167	13,85	16,82	18
	168	13,12	18,75	20
No. 15.	169	15,78	16 .. base	16
	170	14,42	19,16	20
	171	13,32	22,45	24
	172	12,36	26,07	28
No. 16.	173	15,08	12 .. base	12
	174	13,45	15,08	16
	175	12,05	10,79	20
	176	10,95	22,75	24
No. 17.	177	25,80	12 .. base	12
	178	22,87	15,27	16
	179	20,87	18,34	20
	180	18,97	22,19	24
No. 18.	181	23,50	12 .. base	12
	182	20,90	15,18	16
	183	18,90	18,56	20
	184	17,10	22,66	24

Number of the Vessel.	Number of the Experiment.	Time of passing through the last 20 feet.	Weight calculated by the Theory.	Weight shown by the Experiment.
		Half Seconds.	Marcs.	Marcs.
No. 19. First Draught of Water.	185	13,25	12 .. base	12
	186	12,00	14,63	16
	187	10,84	17,93	20
	188	10,07	20,78	24
No. 19. Second Draught of Water.	189	16,00	12 .. base	12
	190	14,13	15,39	16
	191	12,80	18,75	20
	192	11,57	22,95	24
No. 19.-Third Dt. of Water.	193	18,19	12 .. base	12
	194	16,30	14,95	16

Number of the Vessel.	Number of the Experiment.	Time of passing through the last 25 feet.	Weight calculated by the Theory.	Weight shown by the Experiment.
		Half Seconds.	Marcs.	Marcs.
No. 20. First Draught of Water.	195	15,15	7,45	6
	196	13,18	9,86	8
	197	12,45	11,03	10
	198	11,94	12.. base	12
No. 20. Second Dt. of Water.	199	15,98	8,88	8
	200	14,61	10,62	10
	201	13,75	12.. base	12

The remainder of this translation will be given in our future Numbers. C

Art. XXVI.—*Method of ascertaining the Light Draught of Water, previous to the launching of a Ship. Communicated by* Mr. Richard Abethell, *Naval Architect.*

There is an obvious and important connexion between the construction of the hull of a ship, and her future qualities at sea. The height of the centre of gravity of the hull has a considerable influence upon the stability; and its distance from forward or aft, upon the motion of pitching, and the strain of the materials. It is a maxim in ship-building, that the upper

works of a ship, and the parts farthest removed from midships, should be made as light as possible;—but something more than a vague precaution of this kind is required. The centre of gravity of a ship, with respect to length, being fixed, the moment of the weight of the hull, from any vertical plane, determines that of all the other weights. It should evidently be such as to allow the moveable part of them to be placed agreeably to the just principles of stowage: that is, the moment of the hull from a vertical plane passing before or abaft the ship should be, as nearly as circumstances will admit, equal to the difference between the moment of the whole ship and that of the weights on board, of which the moveable parts would be placed in the most advantageous manner for the properties affected by them. Though this nicety of adjustment is inapplicable, in the present state of naval architecture, to an original and untried plan of a ship, yet the principle may be applied with advantage to a ship similar to another, whose best sailing trim is ascertained by experience, should the ballast or other heavy materials have been required to be stowed too near one of the extremities. In this case it ought to be the object of the constructor to remove the centre of gravity of the hull of the second ship towards the same extremity, by a skilful arrangement of the materials, as to scantling, disposition, and specific gravity; taking care, however, not to increase the total weight.

The principal difficulty in finding the light draught of water of a ship consists in obtaining the weight of the hull, and the position of its centre of gravity. The former must be sought, either by deducing the weight of the several portions from their solid contents and specific gravity, or by actually weighing them before they are finally placed in their respective situations in the ship. We must not, however, expect a perfectly accurate result by following either of these methods. If we take the first, it will be necessary to assign and average the specific gravity for each of the several species of materials of which the hull is to be composed; and in proportion to the difference between the estimated and actual averages, will the resulting total weight be erroneous, supposing the calculation to be perfect in all other respects. The latter method would be preferable in point of accuracy, although under the most favourable

circumstances a considerable deduction must be made from the weight of the hull obtained by it, in consequence of the seasoning of the timber materials during the process of building. Moreover, if the weight and position of the centre of gravity of a ship's hull be required, for the purpose of considering their bearing upon the other elements of construction, rather than as a matter of curiosity, this method will be inapplicable, as it will not give the result until the completion of the ship, when it will be too late to make any alteration which may be found necessary. Whichever mode circumstances may lead us to adopt, it will be a very laborious task to obtain the weight of the ship to any great degree of exactness. Nevertheless, an approximation to it, sufficiently correct for the ordinary purposes of construction, may be had by a reference to the light displacement of ships of a similar class already built, the necessary allowances being made for difference of form, dimensions, and other circumstances.

The centre of gravity of the hull being situated in the vertical plane passing through the longitudinal axis, it will be necessary to calculate its perpendicular distance from two planes only, both of which should, for convenience, be at right angles to the vertical longitudinal plane, one of them being parallel, and the other perpendicular, to the keel. The weights of the different portions of the hull, which have been previously found, are multiplied by the perpendicular distances of their centres of gravity from these two planes respectively, and the sum of the products thence arising, in each case, is divided by the sum of all the weights; which will give the perpendicular distance of their common centre of gravity from each of the said planes, and consequently the position of that centre.

These preliminary elements, together with an exact plan of the ship, are the data, by means of which we must proceed to determine her light water section. By the laws of hydrostatics, the portion of the body beneath this section, must displace a quantity of fluid of equal weight with the ship, and having its centre of gravity in the same vertical line with that of the ship. The curves which terminate the body, are not usually of a nature to admit the application of strict mathematical investigation to this subject; we must, therefore, in order to cut off a segment answering the above conditions, have recourse to

methods of trial and approximation. A water line is assumed, as near to the true position as judgment may dictate, and the solid contents and centre of gravity of the displacement under it, are calculated according to one of the rules given by Atwood. The result of the first trial will, in all probability, be a displacement exceeding, or falling short of the proper quantity, and having its centre of gravity on one side, or the other of the line drawn through the centre of gravity of the hull, at right angles with the water line. A second water line must then be drawn, so as to correct the error in the quantity of the displacement, and with such an inclination to the former, as to move the centre of gravity of the displacement in the direction, and, as nearly as possible, through the space required. The effects of this alteration being calculated, if the centre of gravity of displacement should not now fall in the line passing through the centre of gravity of the hull, at right angles with the present water line, a third must be drawn, and so on, until at length the necessary conditions shall be fulfilled.

Instead, however, of thus arbitrarily assuming the angles at which the successive water sections are inclined to each other, which is a tedious and uncertain process, we may by means of the analytical expression, derived from the following construction, find the correct position of the light water line, with tolerable ease and expedition. IOPK, fig. 17, represents a vertical section of a vessel, passing through the longitudinal axis; LM is an assumed, and IK the true water line. A, B, and C, are the centres of gravity of the volumes [1] ISL, KSM, and LOPM, respectively, and G is the centre of gravity of the ship. The lines AQ, BH, GN, and CZ, are perpendicular to LM, and GDE to IK; GZ and CE are parallel to LM, CD to AB, and DF to GN. Also CF is to QH, as ISL (=KSM) is to the displacement LOPM; D is therefore the centre of gravity of IOPK.

Let the displacement LOPM or IOPK$=$V, the volume ISL or KSM$=$A, QH$=b$, CZ$=c$, and the tangent of the required

[1] The areas ISL, KSM, IOPK, and LOPM, are taken to represent the corresponding volumes, of which they are the longitudinal sections. In the same manner the lines IK and LM represent the sections projected into them, and of which they are the axes.

angle of inclination KSM to rad. $1=t$. Therefore $GZ=CN = CF + FE - EN = CF + CF \times \text{tang. } DCE \times \text{tang. } EDF - EN = \frac{bA}{V} \times (1 + \frac{1}{2}t^2) - ct$, very nearly. And if y represents any double ordinate of the water section (projected into LM) perpendicular to its axis, at the distance x from [1] S, on both sides, bA will be very nearly equal to [2] $\int t x^2 y \, dx$.

$$\text{Hence } \int t x^2 y \, dx \times \frac{1 + \frac{1}{2}t^2}{V} - ct = GZ$$

$$\text{Or, by reduction, } t^3 + \left(2 - \frac{2cV}{\int x^2 y \, dx}\right) \times t = \frac{2Gz \times V}{\int x^2 y \, dx};$$

from which we can find the value of t, since Gz, V, and c, are known quantities, and $\int x^2 y \, dx$ may be obtained by measurement and calculation, according to one of Atwood's rules before alluded to. Draw, therefore, the water line IK inclined to LM at an angle whose tangent is t, and making the volumes ISL and KSM equal to each other; find D the centre of gravity of IOPK, and draw DR perpendicular to IK. If DR do not pass exactly through the point G, it will be necessary to correct the position IK of the water line, by a second application of the formula, which will in general be sufficient to ensure accuracy.

Art. XXVII.—*Remarks on the soundness of the Ships of His Majesty's Navy.*

Few subjects have excited greater interest in the country than the soundness and strength of our men-of-war. A natural attachment to naval affairs has given an importance to many unfounded statements and erroneous opinions, which would not have been attached to assertions equally vague and unsupported by evidence on most other subjects. Doubts of the soundness and strength of the ships of the Royal navy require

[1] The point S, which is determined by making the volumes ISL and KSM equal, may, in the first place, be assumed in the centre of gravity of the water section LM, and afterwards corrected, if necessary.

[2] In consequence of the ship's body between the sections IK and LM, not being usually perpendicular to the latter, $\int t x^2 y \, dx$ may not be strictly equal to bA, though sufficient nearly so for the object proposed, the angle ISK being very small, especially after the first trial. On which account also, we may consider the tangent of DCE to be equal to $\frac{1}{2}t$.

only to be mentioned, to excite, not merely the attention of the statesman, but of every well-wisher to his country; and publications which, in every other respect, would be most contemptible, in connexion with this subject, obtain an ephemeral consideration, in order to ascertain whether, amidst a mass of absurdity, some useful observations may not be found.

The general efficiency of ships depends on the design of their form; force of armament; equipment, stowage, and accommodation; the mechanical arrangement of the materials of which they are constructed, and the soundness of these materials. That the science of naval architecture has arrived at the highest point of excellence, both as relates to the forms which govern the qualities of ships and their mechanical construction, it would be unreasonable to suppose: the improvements which have been gradually introduced into the design and construction of our ships, and which are still going forward, place it in the same scale of improvement as other sciences. It is not, however, the intention in these remarks to enter into the consideration of the advancement of naval architecture, but merely to consider the present state of His Majesty's navy, as relates to the soundness of the timber of which it is constructed.

It is a prevalent but an erroneous opinion, that a new and most destructive disease has attacked our ships, known by the alarming epithet, the "dry rot." This name is commonly given to that species of rottenness, to which timber is subject, which is distinguished by the growth of fungus. It appears that this term was not inserted in any official document earlier than in the year 1808.[1] In the year 1811, when the Queen Charlotte, of 100 guns, was discovered to be in a state of premature decay, this term was more generally introduced; since which period it has been too indiscriminately applied, and its effects greatly exaggerated. This disease has, however, existed, although known by different names, and its destructive effects have been felt and regretted, from most remote periods of history.

The magnitude of the British navy gives an extensive field for the destructive operations of this vegetable decay. That the dry rot still exists in His Majesty's ships must be admitted; and it may be presumed, from the nature of timber, that

[1] Knowles "on the means taken to preserve the British Navy."

it ever will, in a greater or less degree, be attendant on large fabrics constructed of timber, whether ships or houses, till the end of the world. It may, however, be most decidedly denied, that its prevalence in His Majesty's navy is such as to create any serious alarm; on the contrary, it may be most clearly proved that the present state of the ships is such as to warrant the most complete satisfaction in their general efficiency and soundness. The constant assertions of those authorities, whose situations render them necessarily acquainted with the general state of the navy, and whose unremitting attention renders them most intimately acquainted with the minute details of the circumstances of His Majesty's ships, are abundantly sufficient to remove the fears of any, who, without an adequate knowledge of the subject, may have allowed themselves to have been unnecessarily troubled by them. But those who are incapable of believing any testimony, however unquestionable, may be convinced of the high state of preservation of the British navy, by a personal examination of their condition. We do not hesitate to say, that such an examination will give a triumphant pleasure to every lover of his country, in the full conviction that British ships are worthy of being manned by British sailors.

The consideration of the rottenness of ships, is frequently much perplexed by unduly neglecting the natural decomposition of timber, and by supposing that the dry rot is too exclusively the cause of the decay. Numerous theories have been given respecting the dry rot, which are generally attended with great difficulty and uncertainty. Fungus is usually considered to be the distinguishing characteristic of this decay, and is sometimes said to be its cause, and at other times its effect, and not unfrequently both; while, by others, it is considered merely adventitious to this disease of timber. The error of most of them is proved by their contradiction; the correctness of any it is more difficult to establish. The least perplexity appears to be, to consider the dry rot as distinctly as possible from the natural decomposition of timber; and to be caused by fungus, propagated by seed, deriving its sustenance chiefly from the juices of the timber, and thereby destroying its strength and tenacity.

All vegetable substances eventually become decomposed by the natural changes which take place in their constituents;

the simple substances of which they are composed continually forming new compounds, and losing in the change many of the properties which they previously possessed. These changes are included in the general term, vegetable fermentation, which terminates in putrefaction, and the total destruction of all the useful properties of the vegetable. Many of the phenomena of vegetable fermentation are now known; but the nature and affinities of vegetable substances must be more fully understood than they are at present, before this process can be clearly and satisfactorily explained. The specific gravity of wood is decreased during the process, by evaporation, and by the formation and escape of carbonic acid gas and hydrogen gas. The wood is eventually changed into a substance possessing very different properties, having lost its hardness, much of its weight, its strength, and its elasticity;—in fact, is become completely rotten.

The circumstances necessary for this process of the decomposition of wood, are moisture and a certain degree of temperature; and the rapidity with which it takes place is dependent on the presence of the different quantities of the necessary attendants. Oak timber when green, is found to contain about one-fourth of its weight of water; and even when well-seasoned, it contains a considerable quantity of it. A small proportion of moisture is sufficient to contribute to its decomposition, which may be either left in it by an imperfect seasoning, or when more completely dried, by being exposed to the occasional action of small quantities of water or vapour. A total immersion in water is inimical to this process. The necessary degree of temperature for the fermentation must be above 32° of Fahrenheit, and this process will be accelerated when the temperature is but little below 45°, and not too high to carry off the moisture rapidly by evaporation. A free exposure to the atmospheric air, tends greatly to check and prevent this process.

In ships in commission the timber is necessarily subject to be in circumstances conducive to its decomposition. A damp atmosphere, an inability of having a free circulation of pure air in many parts of the ship, and a congenial temperature, contribute much to this destructive process. A consideration of these circumstances points out some of the means which may

check or prevent this decay. A prevention of leaks, which admit water into places where it may lie a considerable time on the timber, and as free a circulation of fresh air as can be procured, are two of the most effectual methods that can be adopted to prevent this decay. Pumping out the water from the ship frequently has been found to be a good method of promoting ventilation.

This natural decomposition of timber has been here considered as totally distinct from the dry rot, and as necessarily tending to the decay of the timber of ships, if this destructive disease had not existed. The action of the dry rot, however, in many cases has greatly increased the progress of decay, and in some instances has been a most powerful agent in destroying the strength and efficiency of the fabrics. The rottenness of timber caused by natural decay, forms a nidus very favourable for the growth of fungus, which in many cases becomes an additional and powerful agent in the decay; and it is then a difficult thing, even if possible, to attribute to each agent its relative influence.

The seed of fungi, which is so small as to be seldom if ever sensible to the sight, appears to be very extensively distributed through the vegetable creation, and where the circumstances are favourable to its growth, it vegetates and draws its sustenance in a great degree from the vegetable juices. Where it may not be naturally found, it is frequently deposited by the carbonic acid and hydrogen gases, which, in their escape from decaying timber, carry with them many of these volatile particles. The circumstances necessary for its vegetation and growth, are atmospheric air, moisture, and a temperature above 32 degrees. Its growth is generally on the surfaces of timber, although it is frequently found in the rents and interstices between the fibres of the wood, into which the atmospheric air can penetrate. The circumstances favourable to its growth are the same which chiefly conduce to the natural decomposition of timber, except in its requiring atmospheric air for its growth, which, if necessary at all for the natural decomposition of timber, is required only in such a quantity as is contained in the wood itself;—although a strong current of air generally destroys the fungus.

The numerous nostrums which have been proposed for the prevention and cure of the dry rot, have tended much more to give a false impression of the prevalence of this disease, than to remove or diminish it. Mr. Knowles, of the Navy Office, in his work entitled "An Inquiry into the Means which have been taken to preserve the British Navy," has given an account of different trials which have been made to prevent or cure the dry rot, with the results of the experiments. This work shows that the Navy Board has been always desirous of trying the proposed methods, when they could in any way be shown to possess any reasonable appearance of success.

The methods which are at present adopted in His Majesty's Dock-yards for the preservation of timber, are such as have been suggested by an examination of its nature, and the circumstances in which it is placed in ships, and which have been proved by experience to have been well calculated to produce this desirable effect. The principal methods are, seasoning the timber under roofs; immersion in salt water; taking off the sap from the timber when used; covering the surfaces of the timber with mineral tar and paint, particular attention being paid to all the surfaces which come in contact with each other; and the injection of a mixture of vegetable tar and whitening into ships' bottoms. Placing timber under roofs, the logs being kept apart from each other, is found to be an excellent method of seasoning timber, by admitting a free circulation of air without an exposure to the rain. The immersion of timber in water is found to be an expeditious method of drawing out the juices of the wood; and salt water is preferable to fresh water for this purpose, on account of the antiputrescent property of salt, which, though less effective on vegetable than on animal matter, is useful in checking the decay of timber. Taking off the sap-wood, which speedily becomes rotten, prevents the communication of the decay to the adjoining heart-wood. Covering the surfaces of timber with mineral tar or paint, keeps the timber from being rent by the air, and also prevents the seed of the fungus, which may be in the outer lamina of the timber, from vegetating, by the exclusion of the atmospheric air from it. The seed also which may be deposited from the gases on the surfaces of the mineral

tar and paint, will not vegetate. It is also particularly useful, when two kinds of timber are brought together, by preventing the fermentation which would arise from the union of different vegetable principles. The injection of the tar and whitening into the ships' bottoms, has been found to be of very great benefit in preserving the timbers, by its effectually preventing the growth of the fungus; the openings between the timbers, which would otherwise be imperfectly filled, and the rents in the timbers, in which places the seed of the fungus would be most likely to vegetate, being by this means completely filled, the air, the necessary attendant on vegetation, is excluded. It is probable that the great advantage of the introduction of the injection of tar, &c., into the interstices between the timbers and in the rents of the wood, is not yet fully known. In addition to these preventives, the ships are built and repaired under roofs, which prevent the rain from settling in the rents of the timbers and the openings between them.

In His Majesty's ships in ordinary, particular attention has also been paid to preserve them from decay, by putting temporary roofs over them, taking down parts of the bulkheads in the hold, and leaving out strakes in the deck, and leaving openings in the truss-work between the ports, to promote a free circulation of air through them. These methods have been found very effectual in preserving the soundness of the ships.

It may be remarked, however, that a free current of air through the ships, which is of very great advantage in preventing decay, is attended with the disadvantage of causing the timber to shrink, which is injurious to the strength of the fabric, by destroying, in some degree, the benefit of fitting the pieces of work closely together, technically called "faying well," to give stiffness to the parts of a ship, and thereby brings a great strain on the fastenings. The maximum of advantage is therefore to be obtained, by giving such a circulation of air as may be sufficient to prevent decay, without causing the timber to shrink too much. Experience is tending fast to ascertain the extent to which this principle may be carried with the greatest advantage to the service.

Several ships in ordinary have been mentioned by those who certainly have not taken sufficient pains to ascertain the

truth of their assertions, (intentional misrepresentation we will not suppose to have been practised,) as being in such a state of decay as to call for the examination of the Houses of Parliament;—among the rest, the state of the Bellerophon, of 74 guns, has been mentioned. With that anxiety which marks the deep interest in the naval welfare of our country, for which the department of marine administration is particularly distinguished, it was ordered to take this ship into dock, in His Majesty's Dock-yard at Portsmouth, and to cause the strictest and most extensive scrutiny to be taken of her state. She was opened for survey, even much beyond the usual methods adopted for the purpose of ascertaining the state of ships, and was found not merely sound enough to be fully adequate to any service to which she might be appropriated, but absolutely in a state of perfect soundness. She remained open for several weeks, so that all who wished, might be convinced by examination of her condition. A survey was taken of her by naval officers of high distinction, by shipwright officers, and by carpenters of the navy, whose opinion was unanimous of the excellency of her state.

A Committee of the Honourable Navy Board made the following report to the Board, on the state of this ship, dated 8th July, 1825: "His Majesty's ship Bellerophon (late the Waterloo) having been represented, in a petition to Parliament, and in the public papers, as being in so decayed a state, as to be utterly unseaworthy, we have made the inspection of this ship an object of our most particular attention; and with a view of having the opinion of both Surveyors of the Navy, Mr. Tucker, whose name is subscribed hereto, has joined the committee on this particular occasion. We have the gratification of stating to the Board that our examination of this ship yesterday and to-day has been in the highest degree satisfactory. In the course of our inspection we have proceeded with a minuteness of search, which could not fail to detect decay, had the ship been in the least degree defective. Several planks have been removed from different parts of the bottom and topsides, in places most liable to decay; every beam in every deck has been bored with three holes; pillars in the hold have been removed; tree-nails have been driven out, and the tree-nail

holes searched both in plank and timber. In short, every thing has been done to ascertain the real state of the ship, and we can confidently declare that this severe and unprecedented examination has been made without discovering even a blemish throughout the ship. For the most part, Admiral Sir George Martin the Commander-in-Chief, Captain Sir James Gordon, Captain Inglis, and many other naval officers, together with the Commissioner and officers of the yard, were present at the examination. As our Committee from this comprised both Surveyors of the navy, it appeared a favourable occasion of looking into the condition of some of the ships in ordinary, several of which we visited and found them in the highest state of cleanliness and preservation, with the exception of the Nelson, which has been for some time past off the list of good-conditioned ships, and is intended for repair at a proper opportunity." This report was signed by Sir T. Byam Martin, K. C. B., Comptroller of the Navy. J. Tucker, Esq., and Sir Robert Seppings, Surveyors of the Navy, and J. D. Thompson, Esq., a Commissioner of the Navy.

Commissioner the Honourable Sir George Grey, Bart. made the following report on the state of the Bellerophon to the Committee of the Navy Board, dated July 11, 1825: "Adverting to your letter of the 8th instant, I acquaint you, the Master Shipwright and his Assistants have stated to me, that they have not, in the course of their experience, known any ship to be examined to an extent or in a manner more completely calculated to discover any defects, than the Bellerophon, (late Waterloo;) and notwithstanding the extent to which the examination of that ship has been carried since their report of the 26th April last, they find every part of the ship not only perfectly sound, but without a blemish, in which opinion I most perfectly concur, and which must also have been evident to every one present at the examination; and I have to add, that this ship was put to a most severe test during the unparalleled gale of November last, when she sustained the pressure of the Wellesley and her hulk (a 74 gun-ship) across her hawse, while her stern was aground, for the greater part of the gale, and a strong spring tide, without the hull suffering the *slightest injury*, although the figure-head was completely

destroyed; and had she not been a strong and well-built ship, she must have been materially injured."

Admiral Sir George Martin, G. C. B., made the following report to Vice-Admiral Sir T. Byam Martin, K. C. B,, Comptroller of His Majesty's Navy, dated the 11th July, 1825: "I have much pleasure in complying with your wish, that I should state my opinion of the condition of His Majesty's ship Bellerophon, (late the Waterloo,) as she appeared at the recent survey at which I was present. From the result of the examination, (which was most strict and impartial,) I have no hesitation in declaring, that in my opinion there is not a sounder ship than the Bellerophon in the British Navy."

Captain Sir James A. Gordon, K. C. B., made the following report to Sir T. Byam Martin, dated the 10th July, 1825: "Having been on the dock-side almost every day the shipwrights were preparing the Bellerophon for inspection, and having been present during the first day's survey, I have no hesitation in giving my opinion that she is in the most perfect state. I was prevented attending the second day's survey by indisposition."

Captain Inglis made the following report to Sir Byam Martin, dated the 9th July, 1825: "Having been present at the most particular and very strict survey of His Majesty's ship Bellerophon (late Waterloo) on Thursday last, I am much gratified in being able to give my most decided opinion, that the condition of that ship, in every respect, is in as perfect a state as it is possible for a ship to be."

It might be thought fair to infer, that if such is the state of a ship, which was particularly selected as a proof of the decay of the British navy, the whole of His Majesty's ships might be considered equally sound. "*Ab uno disce omnes.*" But this would be claiming too much. It is enough to say, that the strict examination of this ship and others, which were stated to be rotten, with the constant examination of all the ships in the navy, fully proves their very high state of preservation. It is enough to know, that all that can be done for their preservation, is done, and that the attention given to them is productive of the most satisfactory results.[1] M.

[1] A Captain of the American navy, lately travelling in this country, who

ART. XXVIII.—*Dimensions, and calculated Elements, of some of the Vessels of the Royal Yacht Club, with a few remarks on their Construction: by* JOHN FINCHAM, Esq., *Superintendent of the School of Naval Architecture, in His Majesty's Dock-yard, at Portsmouth.*

THE excellency of many of the vessels belonging to the members of the Royal Yacht Club, and the improvements which are frequently made in the construction of new vessels, added to their list, render the operations of this distinguished club highly interesting and important.

Most improvements have their origin in individual exertion; but the extent and rapidity of their advancement are generally proportionate to the importance attached to them, and the support they receive from men of influence and fortune, who may be interested in their promotion. The advantages derived from the establishment of the Royal Yacht Club, are, in this respect, very great.

The great interest taken at present in yacht sailing, may be considered highly beneficial to our general interests in two respects: the employment of British seamen; and the probable improvement which Naval Architecture may receive from the experience gained by repeated trials of vessels of different forms.

The number of seamen employed on board yachts in this country, is very considerable; and the benefit our royal navy would receive from them, at the commencement of a war, would be great. They become in this employment not only more intimately acquainted with a class of vessels in which the greatest activity is required; but, by the frequent competition in yacht sailing, their energies are increased, and their skill in seamanship improved.

The advantage to be derived from yacht sailing to the general

had just arrived from France, and had collected much information respecting naval affairs, said to one of the conductors of this work, that he considered the state of the British navy better than that of any other nation;—as good, indeed, he said, as it can be.

improvement of Naval Architecture, although not to be immediately expected, in any great degree, is yet completely within the limits of its future operations. The improvement of the forms of vessels particularly adapted for sailing fast, under the favourable circumstances in which yachts are placed, without those great weights which men-of-war necessarily have on board, is, however, the immediate object of those interested in the design and sailing of yachts, to be attended to. When any vessel of this description shall be found to possess very excellent qualities, it may be examined, whether the principles which produce them may be extended to ships of war, or what modifications of them may be made, which may be generally applicable.

It is a vulgar error, that science cannot be advantageously employed, and has done little or nothing for Naval Architecture. Almost every considerable improvement is owing to the practical application of principles founded on scientific investigation. The only cause of the superiority of many of the foreign ships to the English, is, that men of the first scientific attainments in other nations have devoted their labours to the investigation of the principles of Naval Architecture, while in this country, till lately, this important science has been in a great degree neglected.

Practical men are constantly convinced of the advantages of scientific results, and frequently adopt the scientific arrangements which they see generally introduced into works of art, in their own plans. It is probable, that mere practical men despise science much less than they appear to do. It is a bold measure to appropriate scientific results, without a full acquaintance with the principles on which they depend, and sometimes is productive of considerable injury. The adoption of some of the elements of excellent foreign ships in the design of new ships, from a deficiency in the knowledge of all the principles of the original, has, in several instances, produced very different effects from those anticipated.

We know that many objections are brought against the application of mathematical science to ship-building; and some even extend their objections to the practical rules of construc-

tion, and even to the propriety of making a drawing of a vessel previously to its being built.

In some instances, very good vessels are, no doubt, built by the eye, without the use of drawings; long experience in building a particular class of vessels, gives the builder sufficient knowledge of their qualities, after determining their principal dimensions by his judgment, to give the general form which he has found best adapted for obtaining them. Ingenious as such a builder may be, if he possessed scientific knowledge to apply the established principles of floating bodies to his vessels, so as to be acquainted with the principles that governed their properties, his experience would be much more valuable to him, by enabling him to extend the results of his knowledge to the general design of other classes of vessels, with the certainty of their possessing at least all the essential qualities. He would be better able to remedy, in a new design, an error found in an old one, by knowing not only the general form that may have produced it, but, in many cases, by actual measurement making such alterations as to correct the error in the degree required.

To make scientific calculations appear of less value in the design of ships, it is frequently urged, that the slightest alterations will produce the greatest effects;—and even, that ships built from the same drawings have often very different qualities. If it be true, that slight alterations produce great effects, it is certainly of the greatest consequence that we should be fully acquainted with the connexion between these causes and effects, that we may obtain the greatest advantage from them. It is the department of science to investigate the connexion between them, and to give the power of producing the best effects by known and certain means. It is probable, however, that greater changes in the qualities of ships are sometimes supposed to be produced by very trifling alterations in the forms and stowage than really are; and that effects are sometimes attributed to wrong or inadequate causes. As to the difference existing between ships built from the same drawing, it may certainly and easily be shown to proceed from known causes, difference in the quantity or specific gravity of the materials, length of time in building, by which the timber is differently

seasoned, stowage, trim, masting, &c.; and it may be decidedly asserted, that two ships can be built, if required, that shall vary so little as to produce no practical effect whatever.

The only method by which improvement may be justly expected to be made in the forms of vessels, is the same as in all other sciences, a combination of experimental and scientific knowledge.

It is by the application of the philosophy of Lord Bacon, by a legitimate induction from well-established facts and experiments, instead of hypothesis, that most sciences, except Naval Architecture, have advanced to their present state of eminence and usefulness. By the same means which have led to the developement of the laws of nature in other sciences, we may hope Naval Architecture will ultimately be equally benefited. Without them, we may be amused by theories founded on specious conjectures; by romantic and visionary notions of the best forms for the bodies of sailing vessels; but discovery in Naval Architecture will be slow, laws will be seldom developed, and it will be long before our ships will be designed on sure principles.

To apply these principles to the improvement of Naval Architecture, it is necessary to make very extensive calculations on the elements[1] of numerous vessels, and to compare them with the qualities they are known by experience to possess.

The following tables of results of calculations, made on several of the vessels of the Royal Yacht Club, contain such elements as would be chiefly wanted in such a comparison, with the exception of the situations of their centres of gravity, which have not been obtained.

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[1] Mr. Major, Naval Architect, proposed, a few years ago, that a digest should be made of the elements of the ships of His Majesty's navy.—Ed.

Dimensions and calculated Elements of several of the Yachts belonging to the Members of the Royal Yacht Club.

NAME OF THE YACHT	FALCON. Belonging to the Right Hon. Lord Yarborough	COQUETTE Belonging to H. Thorald, Esq.	PEARL. Belonging to the Right Hon. Marquis of Anglesea.	EMERALD. Tender.	NAUTILUS Belonging to the Right Hon. Lord Grantham.	DOLPHIN. Belonging to Captain Browne, R.N.
	Feet.	Feet.	Feet.	Feet.	Feet.	
Burthen in tons (builders' tonnage)	351	150	113	86	103	55
Length on the range of upper deck, from the aft part of the rabbet of the stem, to the fore part of the rabbet of the post	107,2	78,2	64,9	57,25	63,1	55
Length on the water-line, from the fore part of the stem, to the after part of the post	102,8	76,2	65,3	57,8	63,	54,7
Breadth extreme to the thickness of the plank of the bottom	27,4	21	19,54	18,8	19,2	17,6
Breadth of the wing transom	16	14	12	10,5	9,6	8,6
	Feet. Inch.	Feet. Inch.	Feet. Inch.	Feet. Inch.	Feet. Inch.	Feet. Inch.
Draught of water afore	12 9	10 4	6 10	6 4	6 6	5 1½
Draught of water abaft	13 0	10 10	11 4	10 9	9 4	6 10
Greatest transverse section, before the centre of gravity of displacement	9,2	8,5	8,3	6,5	6,45	2,8
Area of the greatest transverse section, in square feet	198,28	124,9	108,2	88,4	82,22	50,14
Area of load-water section	2398,5	1371	1003	815	825,3	619,46
Area of the vertical longitudinal section	1336	793	585	454	522,6	326,4
Displacement in cubic feet	15192	6469	4464	3246	3326	1787,16
Displacement in tons	434	185	127,5	92,7	95,02	51,05
Displacement before the centre of gravity, in cubic feet	7673	3304	2212	1627	1680	910
Displacement before the centre of gravity, in tons	219,4	94,6	63,2	46,5	48	26
Displacement abaft the centre of gravity, in cubic feet	7541	3166	2251	1619	1652	877
Displacement abaft the centre of gravity, in tons	215,5	90,4	64,3	46,2	47,1	25,06
Solid immersed to an inclination of 10 degrees	1277	555	365	290	268	179
Depth of centre of gravity of displacement, below the load-water line	3,8	3,1	2,89	2,51	2,56	1,86
Depth of centre of gravity of the greatest transverse section, below the load-water line	3,7	3,11	3,0		2,71	1,95
	before.	before.	abaft.	abaft.	abaft.	abaft.
Distance of centre of gravity of displacement from the middle of the length, at the water-line, from the fore part of the stem to the aft part of the stern-post	1,7	2,0	2,0	2,16	,45	,2
	abaft.	abaft.			abaft.	abaft.
Distance of the centre of gravity of the load-water line, from the centre of gravity of the displacement	1,4	1,8	,2	,28	,1	,87

Distance of the centre of gravity of the solid, that is before the centre of gravity of displacement, before the said centre	20,24	14,16	11,78	10,3	11,5	9,95
Distance of the centre of gravity of the solid, that is abaft the centre of gravity of displacement, abaft the said centre	20,61	14,76	11,6	10,33	11,63	10,8
Distance of the centre of gravity of the solid immersed to an inclination of 10 degrees from the centre of gravity of displacement	abaft. ,95	abaft. 1,74		before. ,03	abaft. 1,06	abaft. 1,07
Ditto of the part emerged by an inclination of 10 degrees	abaft. ,8	abaft. 1,52	before. ,09	before. ,82	abaft. ,28	abaft. ,55
Distance of the centre of gravity of the vertical longitudinal section, from the centre of gravity of displacement	abaft. 3,8	abaft. 3,1	abaft. 1,74	abaft. 2,1	abaft. 1,7	abaft. 1,7
Height of metacentre	4,7	3,22	2,82	3,13	2,18	3,38
Measure of stability at an inclination of 10 degrees; calculated agreeably to Atwood's method. [See Phil. Trans. of Royal Society for 1798]	,8	,55	,473	,56	,379	,53
Moment of stability at an inclination of ten degrees, (= displacement multiplied by the measure above)	347,2	100,07	60,3	51,5	36,01	27,13
Area of sails	9012	5032	3217	2898	3301	
Moment of sails	424083	157798	89359	79558	95720	
Centre of effort, before the centre of gravity of displacement	6,2	4,0	abaft. ,26	abaft. ,2	3,02	
Height of the centre of effort of the sails above the load-water line	47,05	31,35	27,77	27,4	28,99	
Moment of the effort of sails abaft the centre of gravity of displacement	114311	47848				
Moment of the effort of sails before the centre of gravity of displacement	169111	66388				
Area of sails abaft the centre of gravity of displacement	5721	2700				
Area of sails before the centre of gravity of displacement	3901	2332				
Ballast, in terms of the displacement	,19	,21	,47	,55	,589	,372
Displacement, in proportion to a circumscribed rectangular parallelopiped, contained by the length on the water-line, (from the fore side of the rabbet of the stem, to the after part of the rabbet of the port,) breadth at the water-line, and mean draught of water, to the lower edge of the rabbet of the keel	,47	,42	,44	,4	,435	,41
Area of load-water section, in proportion to a circumscribed rectangle contained by the length and breadth on the water-line	,86	,86	,78	,77	,743	,75
Area of midship section, in proportion to a circumscribed rectangle contained by the breadth at the water-line, and depth from the water-line to the lower side of the rabbet of the keel	,63	,62	,7	,65	,68	,64
Comparative moments of sails in relation to the stability	1221	1577	1489	1560	2659	

MASTS of the FALCON Yacht of the Right Honourable LORD YARBOROUGH.

DIMENSIONS OF FALCON.	Ft.	In.
Length on Water-Line	102	8
Breadth	27	2

SPECIES of MASTS and GEAR.	DIMENSIONS OF MASTS AND GEAR, in Terms of known Quantities. KNOWN QUANTITIES.	Proportions.
Main-mast	Breadth	2.463
Main Top-mast	Main-mast	.612
Main Topgallant-mast	Main-mast Hounded	.283
	Hounded Length Pole	.654
Fore-mast	Main-mast	.918
Fore Top-mast	Main Top-mast	.933
Fore Topgallant-mast	Main Topgallant-mast Hounded	.868
	Hounded Length Pole	.712
Mizen-mast	Main-mast	.865
Mizen Top-mast	Main Top-mast	.701
Mizen Topgallant-mast	Main Topgallant-mast Hounded	.737
	Hounded Length Pole	.65
Bowsprit	Length	.408
Jib-boom	Bowsprit	.714
Main-yard	Length	.544
Main Topsail-yard	Main-yard	.75
Main Topgallant-yard	Main-yard	.464
Fore-yard	Main-yard	.875
Fore Topsail-yard	Fore-yard	.775
Fore Topgallant-yard	Fore-yard	.5
Cross Jack-yard	Main Topsail-yard	.976
Mizen Topsail-yard	Main Topsail-yard	.666
Mizen Topgallant-yard	Main Topgallant-yard	.737
Driver-boom	Length	.392
Gaff	Boom	.743

	Feet.	Ins.
Rake of Main-mast in 12 Feet		6
Rake of Fore-mast do.		2
Rake of Mizen-mast do.		10
Stive of Bowsprit do.	4	6
Fore-mast before Middle Length on Water-Line	.37	
Main-mast abaft	.663	
Mizen-mast	.347	

SAILS of the FALCON.

SAILS.	IN RELATION TO WATER-LINE. Areas.	Heights.	Moments.	IN RELATION TO THE LENGTH. Distance before Middle.	Moments before.	Moments abaft.
Jib	602.56	37.0	22294.72	76.7	46216.35	
Fore-top Staysail	384.07	31.8	12213.43	66.3	25463.84	
Fore-Course	1160.5	28.2	32726.1	38.2	43982.95	
Fore-Topsail	1161.18	58.2	67580.67	38.6	44821.15	
Fore-Topgallant-sail	392.7	85.26	33481.6	38.6	15158.22	
Main-Course	1577.76	27.7	43703.95	6.05		9545.45
Main-Topsail	1436.46	61.5	88342.29	6.25		8977.87
Main-Topgallant-sail	468.7	91.1	42698.57	6.25		2929.38
Mizen-Topsail	649.35	53.9	34999.96	37.4		24285.69
Mizen-Topgallant-sail	237.22	74.9	17767.78	37.9		8990.64
Driver	942.48	30.0	28274.4	52.9		49857.19
Total Areas	9012.98		424083.47		175742.51	104586.22
					104586.22	

Difference of Moments = 71156.29

$$\text{Height of Centre of Effort} = \frac{424083.47}{9012.98} = 47.05$$

$$\text{Distance of Centre of Effort before the Middle} = \frac{71156.29}{9012.98} = 7.89$$

MASTS of the COQUETTE Yacht, belonging to H. THORALD, Esq.

DIMENSIONS OF COQUETTE.

	Ft.	In.
Length on Water Line	76.	2
Breadth	20.	9

DIMENSIONS OF MASTS AND GEAR, in Terms of known Quantities.

SPECIES of MASTS and GEAR.	KNOWN QUANTITIES.	Proportions.
Main-Mast Hounded	Breadth	2.01
Main-Mast Headed	Hounded Length	.178
Main-Topmast Hounded	Main-Mast Hounded	.547
Main-Topmast Headed	Hounded Length	.185
Main-Topgallant-Mast Hounded........	Main-Mast Hounded	.381
Main Royal Pole	Topgallant-Mast Hounded	.547
Main Skysail Pole	Topgallant-Mast Hounded...............	.218
Fore-Mast Hounded	Main Mast..............................	.881
Fore-Mast Headed	Hounded Length	.176
Fore-Topmast Hounded................	Main-Topmast	1.
Fore Topmast Headed	Hounded Length	.185
Fore-Topgallant Mast Hounded	Main-Topgallant Mast	1.
Fore Royal Pole	Hounded Length	.547
Fore Skysail Pole	Hounded Length.........................	.218
Bowsprit..............................	Length	.406
Jib Boom	Bowsprit.................................	.79
Flying Jib Boom	Jib Boom	.98
Main Yard	Length..................................	.538
Main-Topsail Yard	Main Yard	.805
Main-Topgallant Yard	Main Yard...........................	.536
Fore Yard	Main Yard...............................	1.
Fore-Topsail Yard	Fore Yard	.805
Fore-Topgallant Yard....................	Fore Yard..............................	.536
Main Boom	Length	.572
Gaff	Boom	.597
Additional Length for displaying Signals	Gaff......................................	.154
Fore-Trysail Gaff........................	Main Gaff	.596

	Ft. In.
Rake of Main-Mast in 12 Feet	7
Rake of Fore-Mast in 12 Feet	$1\frac{1}{2}$
Stive of Bowsprit in 12 Feet	3 6
Fore-Mast before Middle Length on Water Line	.323
Main-Mast abaft Middle Length on Water Line	.142

SAILS of the COQUETTE.

SAILS.	IN RELATION TO WATER LINE.			IN RELATION TO LENGTH.		
	Areas.	Heights.	Moments.	Distance before Middle.	Moments before.	Moments abaft.
Jibs	385.52	27.1	10447 59	51.3	19777.18	
Fore-Topmast Staysail	193.8	20.84	4038 79	46.2	8953.56	
Fore-Course..........	670 95	17.7	11875 81	25 3	16975.04	
Fore-Topsail	680,67	37.9	25797.39	25.4	17289,02	
Fore-Topgallant Sail..	213 56	57.7	18092.41	25.7	8058.49	
Main-Course..........	942.48	20.	18849.6	11.04	....	10404.98
Main-Topsail	680.67	43.24	29432.17	11.76	....	8004 68
Main-Topgallant Sail..	310.42	63 2	19618.54	12.5	....	3880.25
Driver................	854.46	23.	19645.68	23.6	....	20158.18
	5032.23		157797.98		71053.29	42448.09
					42448.09	
Difference of Moments............					28605.2	

$$\text{Height of Centre of Effort} \ldots\ldots\ldots\ldots = \frac{157797.98}{5032.23} = 31.35 \text{ Feet.}$$

$$\left.\begin{array}{l}\text{Distance of Centre of Effort before}\\ \text{the Middle of Length} \ldots\ldots\ldots\ldots\end{array}\right\} = \frac{28605.2}{5032.23} = 5.68 \text{ Feet.}$$

MASTS and YARDS of the PEARL, EMERALD and NAUTILUS YACHTS.

Dimensions.	Pearl.	Emerald.	Nautilus.
	Ft. In.	Ft. In.	Ft. In.
Length on the Water Line.	63 8	57 8	63 0
Breadth	19 7	18 4	17 5

Dimensions.	Dimensions of Masts and Gear in terms of known quantities. Known quantities.	Pearl.	Emerald.	Nautilus.
Main Mast Hounded	Breadth	2.89	2.89	3.34
.. .. Headed	Hounded Length	.21	.229	.205
Bowsprit	Length	.779	.774	.825
Boom	.. ..	.908	.955	.936
Gaff	Boom	.645	.647	.627
		Inches	Inches.	Inches.
Rake of Main-Mast to Water Line, in 12 feet		13¾	11¼	7½
Stive of Bowsprit		13¾	11½	7½
Main-Mast before the middle. Length on Water Line		.112		.103

SAILS of the PEARL, EMERALD, and NAUTILUS.

PEARL.

SAILS.	In relation to the Water Line. Areas.	Heights.	Momts.	In relation to the Length. Dist.	Momts. before	Momts. abaft.
Mainsail	2148.19	31.04	66679.82	18.6		39956.33
Fore-Sail	442.26	21.5	9508.59	17.7	7828.	
Jib	627.21	21.0	13171.41	39.6	24837.52	
	3217.66		89359.82		32665.52	
					39956.33	

Difference of Moments 7290.81

Height of centre of Effort ......= $\frac{89359.82}{3217.66}$ =27.77ft

Distance of centre of Effort abaft Middle ...... $\frac{7290.81}{3217.66}$ = 2.26ft

EMERALD.

SAILS.	In relation to the Water Line. Areas.	Heights.	Momts.	In relation to the Length. Dist.	Momts. before.	Momts. abaft.
Mainsail	1915.2	31.1	59562.72	16.2		31026.24
Fore-Sail	332.52	20.0	6783.41	13.6	4522.27	
Jib	650.84	20.1	13212.05	32.8	20826.88	
	2898.56		79558.18		25349.15	
					31026.24	

Difference of Moments ....= 5677.09

Height of Centre of Effort ......= $\frac{79558.18}{2898.56}$ 27.4 ft.

Distance of centre of Effort abaft Middle ...... $\frac{5677.09}{2898.58}$ =1.96 ft.

NAUTILUS.

SAILS.	In relation to the Water Line. Areas.	Heights.	Momts.	In relation to the Length. Dist.	Momts. before.	Momts. abaft.
Mainsail	2194.5	32.5	71321.25	19.05		41805.23
Foresail	439.36	22.55	9907.57	16.6	7293.38	
Jib	667.83	21.7	14491.91	37.8	25243.97	
	3301.69		95720.73		32537.35	
					41805.23	

Difference of Moments ....= 9267.88

NAUTILUS.

Height of centre of Effort ....= $\frac{95720.73}{3301.69}$ =28.99 ft.

Distance of centre of Effort abaft Middle ...... = $\frac{9267.88}{3301.69}$ = 2,807 ft.

From having the elements given in these Tables extended to a variety of vessels, and having their sailing qualities stated under numerous circumstances, conclusions might be drawn which would greatly conduce to the improvement of the forms and adjustments of vessels;—the comparison even of a few vessels together is useful, in regulating the elements of a design of a new vessel of the same class. In a future number of this work, it is intended to examine some of the elements of these vessels, with the elements of such other vessels of the Royal Yacht Club, as the writer may be favoured by being permitted to obtain, in relation to their sailing qualities; by which the dependence of their properties on the calculated elements may be shown.

It may be observed that the Falcon, the yacht of the Right Honourable Lord Yarborough, has cast-iron instead of wood chocks under the keelson, made so as to receive at the ends pigs of common ballast. The openings between the timbers of the frame, are filled in with oak and caulked to three inches from the outside, and then filled in with cast-iron fixed with Roman cement, which makes it a solid mass impervious to the water. The use of cement with oak fillings well caulked, in the openings between the timbers, has been sometime common in the royal dockyards, and was applied in the Right Honourable the Earl of Belmore's yacht, the Osprey, about ten years ago; but the application of iron with cement in the openings, was first used in the Falcon, and has since been introduced by Mr. Thorald, in his yacht, the Coquette. The advantages of filling the openings in this manner, are, preventing the openings being filled with dirt and builge water which produce an unpleasant and unhealthy vapour, giving stowage to the hold, giving security to the bottom, more generally diffusing the ballast, and, by lowering the centre of gravity of the ballast, increasing the stability.

Art. XXIX.—*Remarks on English Merchant Ships.*

The low state and rapid decline, which, it is said, exist in our mercantile navy, are subjects of such importance to our very being as a nation, that every circumstance connected with the causes becomes highly interesting. Should the evil increase, we not only sink in what has been called the "first manufacture of the kingdom," but we lose the sinews of our military navy; for the advantage we have hitherto possessed, of a large and unfailing nursery for seamen, is one of the causes which have particularly conduced to our being now the first maritime nation in the world.

It appears that, since the peace, the British mercantile shipping has been in a declining state; and that now, not only have we lost a great part of the carrying trade of foreign nations, but that the English merchants find it to their interest to employ a great proportion of foreign shipping;—to such an extent indeed, that most of the commerce of Liverpool is carried on in American vessels.

There are several causes which, in the natural course of events, have combined to produce this check to our shipping interests.

During the late long war; as we had the command of the seas, we possessed most of the commerce of the world, and the carrying trade was wholly between the Americans and ourselves, their neutrality giving them the same advantages of safety, which we had gained by our power. But when the peace opened the seas to ships of all nations, our shipping interests of course suffered on that account; and also, because in peace there being no causes of delay for convoys, the time expended in the voyages is shorter, and therefore fewer ships are necessary. There are also many causes for the employment of shipping, which, as they belong only to a state of war, cease at its conclusion.

But it appears that the British shipping has suffered far more than the proportion which these considerations would lead us to expect, and that the same causes have not produced the same injurious effects on the mercantile navy of America; but that,

on the contrary, it is the American shipping which is supplanting our own. It therefore becomes a question, why this is the case, and whether it is at all to be attributed to the inefficiency of the ships themselves.

The results of experience and observation have done much in improving the forms of our military navy, and would, no doubt, if applied, have done much for our merchant shipping. But, during the war, merchant ships were obliged to sail in large convoys, and consequently, as the velocity of the whole fleet was regulated by that of the worst sailer, it was of far more importance to the merchant, who had few opportunities for the passage of his goods, to choose those ships which would carry the greatest quantity, than those which possessed velocity, of which no use could be made. This effectually hindered any improvement in the forms of our merchant navy. But the same bar did not exist with the Americans; for their neutrality enabled their ships to sail singly, and consequently it was desirable to attain the greatest velocity which was consistent with the other necessary properties. Thus the peace found America in possession of an immense commercial navy, which, on an average, performed its voyages in one third less time than our own; and although it is attained by some sacrifice of capacity, the result has shown that sacrifice to have been judicious. A similar cause operates against the English shipping, in comparison with that of most foreign powers. The northern nations have long been possessed of a very superior class of merchant ships, the result of the advanced state of the science of Naval Architecture among them, and of the custom of sailing singly on long voyages, even in time of war.

It cannot therefore be wondered at, that when the seas were once more open to all ships, the foreign merchants, whom absence of commerce had impoverished, should choose those which would the soonest allow a return of capital, and at the same time diminish the risk of its loss. Nor is it to be supposed that now when competition is the very spirit of all commerce, it should be a matter of indifference to the British merchant, whether his goods shall be the first in the market, or arrive when that market is glutted.

It appears then, that a great part, at least, of the decline of

our shipping interest, is to be attributed to the inefficiency of the ships themselves.

There are difficulties opposed to the improvement of the forms of merchant ships, which do not exist, at least to the same extent, in opposition to the improvement of the form of men-of-war.

In the design of ships of war, the nature of the service, in which they will be employed, is known, and the lading in comparison with that of a merchant ship, is a constant quantity; it is therefore only necessary to endeavour to obtain a maximum of good qualities in relation to these circumstances. But in a merchant ship, the lading is of such a variable nature, both as to quantity and species, that the ship is at different times under very different circumstances, and subjected to the same trials; thus an East Indiaman is, on her outward voyage, two feet more immersed than on her homeward, and the draught of water of a collier is reduced, at different times, four, five, or six feet, by which the stability is generally very much diminished, and even with the same draught of water the stability may vary very considerably, owing to the difference in the nature and disposition of the lading, and the consequent effect produced on the centre of gravity of the ship; and yet, under these different circumstances, the ships are exposed to the same winds and seas. It is evident that if, when at their proper draught of water, and stowage, they are only equal to the trials to which they are subject, they must be very inadequate to the contest with such a deduction from their powers as this would produce; particularly if their design be not made with a due consideration to this circumstance.

The loss of stability which results from the diminution of draught of water, cannot be compensated by a proportionate arrangement of sail, without incurring other evil consequences. If the quantity of sail, which at all times is small in a merchantman, be lessened, the wind on the increased hull might so counterbalance its effect, that she would be utterly unable to beat off a lee shore, or make any way on a wind.

A ship is not only subject to a loss in stability when lightened, but becomes laboursome on account of top hamper; her rolling motion is more violent, as her diminished depth in the water

decreases the resistance which is opposed to the inclination, and she also generally becomes more leewardly, owing to the difference made in the resultant of the resistance, the diminution of the lateral resistance, and power of carrying sail.

That these effects are to be dreaded is proved by the enormous loss of lives and property, in light merchantmen.

Thus for a ship, which is intended for the various purposes of commerce, to be at all equal to a ship destined only to sail with a constant lading, it must require more art in the construction. But though this is a difficulty which opposes itself, it is no bar to progressive improvement, which is evident, as we are now suffering under the effects of such improvement, made under all the same obstacles, by foreign powers.

That the form of merchant ships may at all be benefited by the application of the knowledge which is possessed of the principles of Naval Architecture, to their construction, a sacrifice in part must be made of those qualities, which have hitherto been considered too exclusively at the expense of others. These are great capacity under small dimensions, and few men to navigate them.

To enable them to sail and work well, their resistance must be diminished and their stability improved, by an increase of dimensions in comparison with the displacement, by which they would gain in velocity, easiness of motion, power to carry sail, and consequently safety. But this would require a proportionally greater quantity of sail, and of course a larger crew to manage them; but as other nations possess better ships than ourselves, and have therefore subjected themselves to the inconvenience of larger crews, that must not be considered as an insurmountable obstacle.

There are other reasons which check any innovation on the present form of our merchant ships. The tonnage, which is the scale according to which the worth of a ship is calculated, and the duties on it levied, involves only the dimensions of length and breadth, so that it can give no idea of the true size, as the depth is not at all considered, and may therefore be increased without limit. Now Chapman gives an expression to which he says the velocity may be considered proportional, it is $\frac{B^{\frac{1}{2}}.\ L^{\frac{4}{3}}}{D^{\frac{3}{2}}}$.

in which B represents the breadth, L the length, and D the depth to the builge; from this expression it is evident that the depth, which is very great in English merchant ships, is the dimension which is most detrimental to velocity.

If a correct scale of solidity were made for every merchant ship, it would enable the duties to be levied according to the quantity of lading on board, instead of according to the dimensions of the ship, whether she be full or empty.

The principal objection to the present mode of calculating the tonnage of merchant ships, is that the relative breadth is given small, to reduce the calculated tonnage in a greater proportion than the lading is diminished. By this means the improvement in the forms of merchant ships is greatly retarded. (See Art. xiii.)

In Sweden, where undoubtedly Naval Architecture is in an advanced state of improvement, and which consequently possesses a fine class of merchant ships, the following method of determining the quantity of lading is adopted. The light draughts of water of the ships are observed, and, together with the area of the light water section, registered. From the light water line to the load, a scale of inches is marked on the ship, by which the alteration caused in the draught of water, by the lading, is exactly known, and the area of the load water section is found by taking the different breadths of the ship at that part, and supposing these breadths to be the ordinates of a parabola the nearest coinciding with the water line, its area is found and assumed as that of the water section; and as the area of the light water section is known, the solid contained between the two may be easily found. Should the sides be much curved between the light and load draught of water, an intermediate section is found.

This method is of course attended with some trouble, but it obviates all the ill effects attendant on any rule for estimating the capacity of a ship, which in any way restricts the dimensions.

As the principal objection to improvement in the merchant shipping is the expense which would be constantly incurred by a ship of an improved form, it would be advisable to endeavour to diminish it, and even if possible to make the possession of good properties conducive to this end.

By the improvement in the form of ships, the danger of navigation is decreased; consequently the underwriter, running less risk, should receive a proportionally less premium. Now as it is established that the general form conducive to stability, and consequently to safety, is that which is relatively full between wind and water, and lean below, ships which are of this form should pay a diminished rate of insurance; and we may deduce from the parabolic system of construction, which is described in Art. XVIII., the means of ascertaining the degree of relative fulness any ship possesses, or of forming a scale of safety.

One of the exponents which are used in the parabolic system is a measure of the comparative fulness of the body, with the area of the load-water-section. To get its value, the areas of the different horizontal sections are supposed to decrease as the abscissas to a parabola, of which the draught of water to the builge in midships is taken as the greatest ordinate, and consequently the displacement is equal to the area. If n be the exponent of the parabola, D the displacement, d the draught of water to the builge, and a the area of the load-water-section,

$$\frac{n}{n+1} d\,a = \mathrm{D} \text{ or } n = \frac{\mathrm{D}}{d\,a - \mathrm{D}}$$

Which value of n, by showing the order of the parabola, is a measure of the degree of fulness of the body, in comparison with the area of the load-water-section. If, therefore, the duties were levied in proportion to the stowage of the vessel, and the premiums of insurance paid according to the same proportion, but varying for different vessels, inversely as the exponent which has been just described, there would be an inducement to improvement, and the insurance would be correctly in proportion to the risk, with reference to form; as the necessity of great displacement would prevent the adoption of any extreme case.

It is probable, that in the event of another war, steam-boats will be in very general use, both as privateers and men-of-war; in which case, the only means of safety to a ship must be in the resources she possesses; for convoy can be but of small service in the protection of a large fleet from the attacks of steam-boats. This will probably make a considerable change in the nature of the transmission of our commerce, and it will

become necessary for the merchant-ship to be an armed vessel; in which case the additional crew and additional velocity will be necessary, both for resistance and flight: for though the former alternative would be the only resource in calm weather, yet in a sea, a good sea-boat might easily escape.

Thus, by an improvement in our commercial navy, "[1]To the merchant there can be no doubt, that the most important benefit would accrue, in the increased security for the transmission of his property. By the underwriter, the advantages would be still more directly and sensibly felt, in the protection that would be afforded him against the absolutely fraudulent system under which, in reliance on the quality of ships, he has hitherto been exposed to enormous loss, arising from the acceptance of risks at rates of premium calculated on the supposition of the ships being good, while, in fact, he has been, from the inferiority and in many cases insufficiency of those ships, incurring a much higher degree of hazard, for which he has received no adequate compensation. Nor would the justice done to the fair and respectable ship-owner be less important, by assigning to his well-constructed and well-repaired ship the character her quality deserves, instead of her being subjected to indiscriminate classification with those of inferior description, the comparative value of his property would be improved. By the diminution of risk, consequent on the elevation of quality, the burthen of insurance may be expected to be diminished; and by the advancement in general estimation, the ultimately extended employment of British shipping in distant voyages, may be fairly anticipated." And in addition, it is a measure of national importance to ensure, by possessing a large commercial navy, future resources for our military navy.

It is intended to resume the consideration of the improvements of merchant ships in a future Number, when a comparison will be made between the elements of our merchant ships and those designed by Chapman. C.

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[1] See Report of the Committee of Merchants, Ship-owners, and Underwriters of London, and of the Representatives of the principal Out-Ports in Great Britain, appointed on the 22d of January, 1824, to collect the fullest information on the Subject of the System at present pursued in the Classification of Merchant Shipping. Dated the 8th of February, 1826.

PAPERS

ON

NAVAL ARCHITECTURE,

&c.

ART. XXX.—*Brief Sketch of the Progress of Naval Architecture, with some Observations on the Dimensions and Midship Sections of Ships.*

NAVAL Architecture, like other arts, in its earliest ages, before the principles on which it depended were known, could have presented little more than the rude efforts of unassisted reason. Experience must have early taught some of the first elements of the art. A coincidence in the results of similar accidents, would speedily lead to an acquaintance with some of the simplest rudiments of knowledge, which would be soon taken advantage of, in the construction of vessels. The acquaintance with a few insulated facts are, however, insufficient to entitle it to the name of science; from the period when some of its principles became known, and subject to correct measurement, the history of its science may be dated. That trees, for instance, would float on the water, must have been immediately suggested by observation; but the laws which regulated the proportion of the weights supported in relation to the specific gravity of the tree, and to its magnitude, it was left to the investigations of philosophy to develope.

From numerous causes, the desire might early arise to cross the narrow rivers and lakes, by which the land is intersected; and it is easy to suppose, that the attempt to gratify such a desire would be soon successful. From a raft of unhewn logs, which was probably the first floating body used for conveyance on the water, the progress was natural and easy, though not

inconsiderable, to a hollowed tree,—which is the present form of the canoes of the least-cultivated Indians. It is not difficult to conceive the gradual improvement in canoes, and the progress to the ingenious construction of boats; and as circumstances required, and the advancement of some of the mechanical arts permitted, to the construction of larger vessels. The different purposes for which they were required, dictated accordingly peculiarities of construction: vessels intended for fast sailing, or for burden, were given, as far as could be discovered, the forms conducive to such properties.

With the improvement of vessels, the means of propelling them through the water varied, from a pole, which was probably the first instrument used for the purpose, to oars, and eventually to sails;—though in ancient marine architecture, oars continued generally to be preferred to sails in ships of war, partly from want of skill in the use of sails, but chiefly from the nature of the warfare, in which the ships were engaged.

> Inventa secuit primus qui nave profundum,
>   Et rudibus remis solicitavit aquas,
> Tranquillis primum trepidus se credidit undis,
>   Littora securo tramite summa legens;
> Mox longos tentare sinus, et linquere terras,
>   Et leni cœpit pandere vela noto:
> Ast ubi paullatim præceps audavia crevit,
>   Cordaque lanquentem dedidicere metum,
> Jam vagus irrupit pelago, cœlumque secutus,
>   Ægæas hyemes, Ioniasque domat.[1]

To ascertain, with any certainty, the forms, or even the dimensions of the vessels, famous in ancient history, is at present impossible; as most of the accounts we have of them are involved in mythological fable, and the statements of their magnitude not only often inconsistent with each other, but evidently so exaggerated, as to be beyond the limits of the capabilities of the subject. The extraordinary respect shown to those who made any considerable improvement in ship-building, and their being frequently numbered with the deified heroes, and even their works being translated into the heavens, show at the same time the great admiration with which naval architecture was viewed, and the general ignorance of the

[1] Claudian, Præfat. in Rapt. Proserpina.

people concerning the principles of the science. The story of Triptolemus, who, in a time of dearth at Athens, was feigned to have brought supplies on a winged dragon, is one of the numerous instances in which fancy has clothed the successful attempts of the first ship-builders.

The first people probably who improved naval architecture, so far as to build ships capable of carrying considerable lading, and who made sufficient progress in navigation to enable them to brave the dangers of the sea, were the Phœnicians; whose small extent of territory made commerce necessary to their political importance, and whose situation on the eastern coast of the Mediterranean gave them every facility in promoting their commercial interests. The Syrians, who possessed similar advantages, preferring inland commerce, paid less attention to their maritime affairs, and thus allowed the Phœnicians to obtain a naval superiority, which, by increasing their riches, enabled them long to maintain their glory. The Egyptians perhaps made some of the first steps in the construction of vessels; but from confining their navigation at first to the Nile, from a national prejudice against the sea, were not likely to make such improvements in the forms of their vessels, as the adventurous Phœnicians found necessary for their distant voyages. Circumstances concurred in giving the naval superiority to this mercantile nation, which appears to have monopolized the carrying trade of the greatest part of the then known world.

The Greeks probably obtained most of their knowledge of ship-building from the Phœnicians, which they prosecuted with great success: they soon became so powerful, that they obtained most signal victories over the Persian fleets, which were chiefly managed by the Phœnicians. The battle of Salamis was an important instance of their success; and the battle at Hydrope, where Cimon destroyed a Phœnician fleet of seventy sail, shows that they even surpassed their instructors in naval power. They however almost exclusively employed their naval acquirements for purposes of war, commerce being but little attended to by the states of Greece.

As the redundant population of Phœnicia soon rendered colonization necessary, the art of ship-building was carried to

other countries, where circumstances dictated, according to the interests of the colonists, greater or less attention to its improvement. The founders of Carthage carried with them the maritime spirit of their mother country; and for a short time this state possessed the superiority of naval power in the Mediterranean. From them the Romans learnt the art of ship-building, by constructing vessels according to the form and mechanism of a Carthaginian ship wrecked on their coast; which they speedily carried into such an extensive practice, as to be able to meet their rivals successfully on the sea, and eventually to crush their power.

The destruction of the Roman Empire by the Goths and Vandals contributed to retard naval improvement. For a long time, the contests in which the world was engaged were chiefly confined to warfare on land. Although the Saracens in several instances raised large fleets, which were necessary to the prosecution of their wars, yet their decided attachment to military operations on land, turned aside the energies of the contending nations from naval affairs.

Under the reign of Charlemagne, marine architecture again began to advance, by the attention paid by the Venetians to naval commerce, who thereby gradually rose to great importance, and acquired very considerable naval power; which was afterwards shared by their rivals the Genoese. The Hanse Towns also participated with the states of Venice and Genoa in the chief commercial and naval power of the Mediterranean.

Though England for a long time attended less to marine affairs than many other nations, and was not particularly distinguished for superiority in that power, for which she has since been so famous, and which happily is still increasing; yet we find that in numerous instances, in her early history, she has been successful in naval engagements, and that her force has generally been respectable in the scale of the naval power of nations.

Among the northern nations of Europe, Denmark took a lead in naval enterprise; and the perilous nature of the naval service in her seas, obliged her to pay particular attention to the construction of vessels.

Most nations whose situation enabled them, paid, at different

times, greater or less attention to naval affairs. The Normans, as early as the eleventh century, rose to some consequence in naval power. The fleets of Spain, at an early period, were very considerable; and their ships were remarkable for their size, being superior to those of most other nations. The carracks of Spain, in the fourteenth century, are described by historians as of very great magnitude.

To those states which paid the greatest attention to commerce, ship-building is principally indebted for its improvements; but while many participate in the honour, Venice and Genoa deserve to rank eminently high in the list of the chief promoters of this art.

The form of the Phœnician galleys probably differed but little from that of the Venetian galleys, before the introduction of cannon on board vessels. The only means of gaining any acquaintance with the forms of the Phœnician vessels, is from the impression on their coins, which was the figure of a vessel's prow,—at best but a very vague and unsatisfactory evidence. Very little difference is discernible in them from those of the Romans, except in the more profuse decorations in the vessels of the latter. In the Greek and Roman galleys, we find no material difference of form: the improvements made in these vessels, rather consisted in alterations and inventions calculated for attack and defence, than in any alteration of form to enable them the better to endure the effects of the winds and waves.

The principal peculiarity of the galleys, was a very small breadth in proportion to their length. Both the ancient and modern galleys, being chiefly built for rowing, were generally without any transverse inclination; and even when moved forward by the wind, from the little advancement made in the disposition of sails, none having been then introduced which could be close-hauled, the vessels sailing with the wind free could be but little inclined from the upright by its force, so that they would require but little stability, which is chiefly obtained by a considerable relative breadth. This important difference in the moving power of these vessels, allowed them to have the best forms for great velocity in a direct course, which is possessed by vessels having great length

in proportion to their breadth. The principal cause, however, of the very great length given to the galleys, was the conveniences it afforded to a great number of rowers. In some cases, the breadth of the galleys was not a seventh of their length. The dimensions of the ancient Trireme were 65 feet in length, to 9 feet in breadth; larger galleys were in the same proportion: the length being generally between 7 and 8 times the breadth. The immense galley of Ptolemy Philopater, is said to have been in the same proportion.

It may be observed, that many steam-boats used for inland navigation do not very materially differ in their proportions from those of some of the galleys.

Vessels built for burden were, however, built proportionally broader than those only intended for war, in order to give them greater proportional capacity for stowage; which form also gave them more stability, and contributed to their greater safety, in the dangers to which they were exposed in more distant voyages.

The main section, or, as it is commonly called, the midship section, probably from being very near the middle of the length, of an ancient galley, was perhaps similar to Fig. 18, taken from Charnock's Marine Architecture. [1] Fig. 19 is the midship section of the model of a Roman vessel, presented to Greenwich Hospital by the Right Honourable Lord Anson, taken from a marble model, which was found in the Villa Matthei in the sixteenth century. It may be observed, that the length of this vessel, at the probable water-line, was between three and four times the breadth, a much smaller proportion than was usually given to their galleys;—although the former proportion of the length to the breadth of the ancient galleys being taken from the extreme parts of the prow and stern, which had very great rakes, makes the length appear much greater in proportion to their breadth, than the present method of estimating these dimensions would give.

The principal peculiarity of these midship sections, is the continuance of the curve of the body above the water-line, so that the top-sides projected further from the middle line in

[1] Charnock's Mar. Arch., vol. i., page 114.

proportion to their height. This projection of the sides afforded convenience for the different tiers of oars, by which they were generally propelled.

The great difference between the state of naval affairs, in ancient and modern times, with the extensive improvements which have been made in the last few centuries, and are still proceeding, are to be attributed to the discovery of the properties of the magnet, with its application to the mariner's compass: a discovery which has contributed more to the extension of human power, than any other in the history of the world. The adventures of ancient heroes, without this invaluable instrument, were necessarily confined to coasting voyages, which were attended with greater dangers, than, with its aid, are generally experienced in sailing round the globe. That this instrument was not known to the ancients appears, as Mr. Locke observes in his History of Navigation, from the history and practice of former ages: from "history, because it could not but have made some mention of a thing so universally useful and necessary; and practice, because it is well known no such voyages were then performed, as are now daily by the help of the compass." He observes, that it has been sufficiently proved, "that in all former ages they were but coasters, scarce daring to venture out of sight of land; that if out at night, they had no other rule to go by but the stars; and what is still more, it is manifest they scarce ventured at all to sea in the winter months." That this is so, appears by Vegetius, (Lib. 4,) where, speaking of the months, he says,—"The seas are shut from the 3d of the ides of November, to the 6th of the ides of March, and from that time till the ides of May it is dangerous venturing to sea." Whatever difficulty there may be in ascertaining whether the properties of the magnet were known earlier in other parts of the world, it appears just to consider the discovery of the mariner's compass in Europe due to John Gioia, a Neapolitan, about the year 1300. It does not, however, appear that this instrument came into general use immediately on its discovery, nor is it known when the different nations introduced it generally into their service. It is certain that a considerable time elapsed before any distant voyages were undertaken; Spain, Portugal, England, and Holland, were the first nations which

took advantage of the use of this instrument, to enable them to make distant voyages.

The discovery of America by the Spaniards under Christopher Columbus, a Genoese, and the first voyage made to the East Indies by the Portuguese under Vasco de Gama, at the close of the fifteenth century, which were immediately followed by the English, Dutch, and French discoveries in America and Asia, directed the general attention of Europe to the improvement of naval architecture, and of maritime affairs generally. We find by the accounts given of the three vessels, with which Columbus undertook the voyage, that the largest was of very small burden, and the two others little better than some of our present fishing-boats; and that they were all so badly built and equipped, that he was obliged to repair them soon after the commencement of his voyage, at the Canary Islands. Under all the circumstances of the undertaking, we are astonished alike at the genius which designed it, the boldness which attempted it, the courage and resource which sustained its difficulties, and the success which crowned its labours.

The extended voyages which after this period became common, necessarily caused a greater degree of attention to be paid to the construction of ships than preceding circumstances had required. From that time to the present, a period of not much above three centuries, naval architecture has improved more than in all preceding ages.

Next in importance to the discovery of the mariner's compass, and affecting even more the forms of ships of war, was the introduction of cannon on board vessels. At first, a few were mounted on the deck of the galley, to be fired over the gunwales, which were very low; soon afterwards, the top-sides were raised, and port-holes cut through them; which appears to have been the only alteration made in the construction of the galley by this introduction. The galleon and galleas were vessels built in some respects after the form of the galley, but constructed to carry much greater weight of metal. The galleon was shorter and broader than the galley, with much greater height of top-sides; the galleas was in all respects much larger than the galley, carrying more guns and of greater calibre. The increase of breadth in proportion to the length

given to these vessels, was necessary to counteract the effect, which the weight of cannon and high upper works would have in diminishing their stability. A great alteration in the form of the curve of the top-sides was made in these vessels: instead of the top-sides falling out above the water, as in the galley, they were constructed with a great falling inward toward the middle line of the vessel, called tumbling-home; which was given in order that the weight of the cannon might not cause too great a strain on the connexion of the beams with the sides of the vessels. This alteration in the form of the top-sides was carried to an absurd extent by the Venetians and other States that imitated them in the construction of vessels: in some cases the breadth of the vessels at the top-sides was not more than half the extreme breadth of the same transverse sections,—which was a little above the water-line. By comparing Fig. 20, which represents the midship section of a galleon, with Fig. 18 and 19, the alteration which was made in the forms of the midship sections in consequence of the introduction of cannon on board vessels, carrying a considerable weight of metal, is apparent. That the curve of the bottom of the galley, shown in Fig. 18 and 19, could not have been continued to a considerable height above the top-sides, without greatly weakening the connexion of the beams with the sides of the vessels, is readily admitted; but that the tumbling-home which was given was excessive, is also evident, by comparing it with the tumbling-home given to some of our modern ships, shown by the ticked line *a b*, (Fig. 20,) which carry the greatest weight of metal, and are at least sufficiently strong not to suffer materially from the immense strain of the much greater weights which they sustain.

Ship-building began to be more particularly attended to in England in the reign of Henry the Seventh, who commenced the Royal Navy of England, by building the Great Harry, which is said to have been the first ship built with two decks in England. In the succeeding reign the foundation was laid for an extensive Royal Navy; and the Admiralty and Navy Offices were constituted for the direction of naval affairs. In the early part of this reign we find the Regent of 1000 tons burden, with the Mary Rose of 500 tons, and several other

vessels. The Regent being burnt in an engagement with the French fleet in 1512, Henry the Eighth ordered a ship called the Henry grace de Dieu, to be built of equal tonnage, which carried 700 men. This ship continued in the list of the Royal Navy in the second year of Edward the Sixth, but is omitted in the list[1] of the Royal Navy in the sixth year of his reign, in which the first ship is called the Edward. It does not appear improbable, that the Henry grace de Dieu and the Edward were the same ship, the name being merely changed in honour of the new king.

The principal defect of ships at this period, appears to have been too great height above the water in proportion to the extreme breadth, while at the same time the lower tier of guns was much too near the water's surface. The loss of the Mary Rose is attributed to the defect of her ports being very near the water: Sir Walter Raleigh says that they were within sixteen inches of the water. Grafton, describing her loss, says, "after the departyng of the Englishe navie from Newhaven, the admirall of Fraunce, called the lorde Danibalt, a man of great experience, halsed up his sayles, and with his whole navie came to the poynt of the Isle of Wight, called Saint Helene's poynt, and there, in good order, cast their ankers, and sent xvi of his galies daily to the very haven of Portesmouth. The English navie lying in the haven made them prest and set out towards them, and stil the one shot at the other. But one day above al other, the whole navie of the Englishemen made out and pursued to set on the Frenchmen, but in their setting forward, a goodly shippe of Englande, called the Marye Rose, was by to much folly drowned in the middes of the haven; for she was laden with to much ordinance, and the portes left open, which were verye low, and the great ordinance unbreeched, so that when the shippe should turne, the water entered, and sodainly she sanke."

This accident led to the raising the lower deck ports higher from the water. Some other improvements were made soon afterwards in the equipment of ships; the greatest of which

[1] See these two lists in Derrick's Memoirs of the Royal Navy; the first of which is taken from the sixth vol. of the Archœologia, and the other from the eighth vol. of Pepys's Miscellanies.

was, perhaps, the introduction of striking top-masts. Sir Walter Raleigh enumerates these improvements. He says, "whoever were the inventors, we find that every age has added somewhat to ships; and in my time, the shape of our English ships has been greatly bettered. It is not long since the striking of the top-masts, a wonderful ease to great ships, both at sea and in the harbour, hath been devised, together with the chain-pump, which taketh up twice as much water as the ordinary one did. We have lately added the bonnet, and the drabler, to the courses; we have added studding-sails,—the weighing anchors by the capstern. We have fallen into consideration of the length of cables, and by it we resist the malice of the greatest winds that can blow. Witness the Hollanders, that were wont to ride before Dunkirk with the wind at north-east, making a lee-shore in all weathers: for, true it is, that the length of the cable is the life of the ship in all extremities; and the reason is, that it makes so many bendings and waves, as the ship riding at that length is not able to stretch it, and nothing breaks that is not stretched."

The proposal of Sir Robert Dudley, at the end of the sixteenth and beginning of the seventeenth century, to divide the ships of war into seven classes, was a great attempt at improvement. He gave the dimensions of these vessels according to the services for which he intended them; all of them being constructed to draw very little water. The length of his first class, called the galleon, was four times the breadth; the length of his other vessels gradually increased in proportion to their breadth; the seventh class, called the passa-volante, entirely intended for velocity, having its length in the extravagant proportion of ten times its breadth. This proportion between the length and breadth of his vessels, was a defect so great, as far to counterbalance the improvements in some other points recommended in his plans,—which were the reduction of the excessive heights of the sterns and forecastles, (though in his galleon and rambargo the sterns were still very high,) economy in ornamental work, and the increased elevation of the lower tier of ports above the water. The tumbling-home of the top-sides he retained in his vessels. He, however, admitted that these vessels were incapable of carrying merchandize, or even

the stores which ships of war require in long voyages; but he considered that they would be particularly adapted for navigating the Mediterranean. That their defects would have been less felt in the short voyages in this sea may be admitted, but their inapplicability to general service was so serious an objection to his plans, as totally to prevent their adoption.

It appears that at the commencement of the seventeenth century, there existed great similarity in the ships of all nations, constructors having adhered to the forms of the Venetian vessels, making only such alterations as the depth of water on the different coasts, and a few other circumstances rendered necessary. The principal improvement which took place in ship-building in the reign of James the First, was made in the construction of the Royal Prince, built in 1610, under the direction of Mr. Phineas Pett,[1] who was a master shipwright, and afterwards a Commissioner of the Navy. The great and unnecessary projection of the prow, which up to that time was given to vessels, was reduced in this ship to nearly the same as in our present line of battle ships; and the great extension of the quarter galleries, and extravagant height of the stern and forecastle, were reduced to a moderate proportion. In a drawing which is given of this ship in Charnock's Marine Architecture, the whole figure and general appearance, with the exception of the great quantity of ornamental work, are not very dissimilar from those of our present two-decked ships. "The keel of this ship was 114 feet long, and the cross-beam 44 feet in length. She will carry 64 pieces of great ordnance, and is of the burden of 1,400 tons.[2]" She was the largest ship which at that period had been built in England.

In the reign of Charles the First a much larger ship was constructed, called the Sovereign of the Seas. Heywood says, in his account of this ship, addressed at that time to the King, that "she was in length by the keel 128 feet, or thereabout, within some few inches; her main breadth 48 feet; in length,

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[1] Previously to his apprenticeship to ship-building he was a Master of Arts at Emanuel College, Cambridge. The attention this gentleman paid to ship-building, and the improvements he introduced into the practical construction of vessels, entitle him to the highest respect as a promoter of this science.

[2] Stowe's Annals.

from the fore-end of the beak-head to the after-end of the stern, *a prora ad puppim*, 232 feet; and in height, from the bottom of her keel to the top of her lanthorn, 76 feet: bore five lanthorns, the biggest of which would hold ten persons upright; had three flush decks, a forecastle, half-deck, quarter-deck, and round-house; she hath also galleries besides." This ship was found so defective in stability, that it was necessary to reduce her a deck lower, after which alteration she proved sufficiently stiff, and was considered a good ship. The defect arose from the weights being too great above the water, by which the centre of gravity was raised too high, and the stability consequently reduced; the breadth of this ship bearing as great a proportion to the length as ships generally require.

Particular attention was paid, during this reign, to naval affairs. A general increase of the dimensions of the ships of the Royal Navy was introduced at that time, by which it was greatly improved. The form of the ships' bodies was also considerably improved, by reducing the excessive fulness of the bows and sterns, which had been originally taken from the Dutch.

Fuller, in his History of the Worthies of England, mentions some of the peculiarities of the ships of different nations at this period, and considers English ships superior to most others. He says that ours were built so as to keep to the wind better than those of most other nations, particularly than those of the Dutch, which were too "floaty and boyant;" and that our ships were lower than the Spanish ships, whose "loftiness makes them fairer marks to our shot. Besides, the wind hath so much power of them in bad weather, so that it drives them two leagues, for one of ours, to the leeward, which is very dangerous upon a lee-shore." The carvils and caracts of Portugal, he says, "were the veriest drones on the sea." The best ships of the French, he observes, were of Dutch building. The Turkish frigates, designed and built after the English manner, he mentions as good sailers. He says that the models of all our large ships were originally our own, but that we had the model of our frigates from the Dunkerks, which however

had been so greatly improved as to be much better sailers than the originals.

In 1677 the dimensions of the different classes of ships were established by government, the Henry, Katherine, and other ships, having been built so deficient in stability, that they were unserviceable till they were girdled, the builders not having well considered, Mr. Pepys observes, "that breadth only will make a stiff ship." It appears, however, that several ships were built, after this establishment, of larger dimensions than it directs. The relative breadth in these dimensions is less than that given in subsequent establishments.

Sir Richard Haddock, Comptroller of the Navy, in 1684, directed a scientific inquiry to be made into the solid content immersed in the water, of a ship of each class, when laden, from a fourth to a sixth-rate; and by subtracting the weight of the ship's hull, when launched, from the total displacement, to determine the true burden in tons it will carry, and to compare this correct tonnage with the nominal tonnage[1] calculated by the rules then in use. This appears to have been the first attempt at the scientific investigation of the elements of ships in this country.

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[1] The rules for estimating the tonnage of ships appear to have varied very much at different periods, and to have been very indeterminate before 1719, when a new method was settled by the Lords Commissioners of the Admiralty. The tonnage of the Royal Sovereign was estimated in different lists at 1637, 1556, and 1141 tons burden.

The Dimensions and Displacements of several classes of English Ships, calculated in 1684.

	4th rate. 1st class.		4th rate. 2d class.		5th rate.		6th rate. 1st class.		6th rate. 2d class.	
	Feet.	Inch.	Feet.	Inch.	Feet.	Inch.	Feet.	Inch.	Feet.	Inch.
Length on the gun-deck, from the rabbet of the stem to the rabbet of the stern-post	124	6	116	6	103	9	87	8	70	0
Main breadth to the outside of the outboard plank	35	0	32	9	28	8	23	6	21	6
Depth in hold, from the ceiling to the upper side of the beam	14	9	13	2	11	4	10	9	9	10
Draught of water afore	14	6	13	6	12	0	9	8	5	6
Draught of water abaft	15	10	15	0	13	0	10	8	9	6
Solid content below the load-water-line, in cubic feet	29814,0		22346,00		13195,0		8906,00		6790,0	
—— —— in tons	851,8		638,45		377,0		254,45		194,0	
Weight of the hull at launching, in tons, estimated by judgment	418,0		314,00		161,0		120,00		98,0	
Burden which the ship will carry, in tons	433,8		324,45		216,0		134,45		96,0	

It was at the same time recommended to give greater extreme breadth, and a more rising floor. Fig. 21 shows the proposed alteration; *a b c d* is the midship section then in general use, *a e f g* the midship section proposed.

During the short reign of James the Second great attention was paid to naval affairs; especially as related to the materials requisite for building and repairing ships, and to the necessary possession of stores for the service. The dimensions and forms of ships remained without any particular alterations.

The general dimensions of ships continued nearly the same during the reign of William and Mary. The Royal William, built in 1692, a first rate, was however only 1340 tons burden; but we find that at the end of the reign of William, the total burden of the seven first rates was 10,955 tons, averaging 1565 tons each, differing but little from the establishment of 1677.

The following table of dimensions, established at different periods, will show the gradual increase of the dimensions of the ships of the Royal Navy.

DIMENSIONS OF SHIPS.

An Account showing the Dimensions established, or proposed to be established at different times, for Building Ships.[1]

	ESTABLISHMENT OF								PROPOSED IN				Establishment of 1745	
	1677		1691		1706		1719		1733		1741		1745	
	Feet.	Inch.	Feet.	Inch.	Feet.	Inch.	Feet.	Inch.	Feet.	Inch.	Feet.	Inch.	Feet.	Inch.
100 GUN SHIPS.														
Length on the gun-deck	165	0					174	0	174	0	175	0	178	0
—— of the keel for tonnage	137	8					140	7	140	7	142	4	144	6½
Breadth extreme	46	0					50	0	50	0	50	0	51	0
Depth in hold	19	2					20	0	20	6	21	0	21	6
Burthen in tons	1550						1869		1869		1892		2000	
90 GUN SHIPS.														
Length on the gun-deck	158	0			162	0	164	0	166	0	168	0	170	0
—— of the keel for tonnage					132	0	132	5	134	1	137	0	138	4
Breadth extreme	44	0			47	0	47	2	47	9	48	0	48	6
Depth in hold	18	2			18	6	18	10	19	6	20	2	20	6
Burthen in tons	1307				1551		1566		1623		1679		1730	

[1] Taken from Derrick's Memoirs of the Royal Navy.

	ESTABLISHMENT OF								PROPOSED IN				Establishment of 1745.	
	1677.		1691.		1706.		1719.		1733.		1741.			
	Feet.	Inch.	Feet.	Inch.	Feet.	Inch.	Feet.	Inch.	Feet.	Inch.	Feet.	Inch.	Feet.	Inch.
80 GUN SHIPS, WITH THREE DECKS.														
Length on the gun-deck			156	0	156	0	158	0	158	0	161	0	165	0
—— of the keel for tonnage					127	6	128	2	127	8	130	10	134	10¼
Breadth extreme			41	0	43	6	44	6	45	5	46	0	47	0
Depth in hold			17	4	17	8	18	2	18	7	19	4	20	0
Burthen in tons			1100		1283		1350		1400		1472		1585	
70 GUN SHIPS.														
Length on the gun-deck	150	0			150	0	151	0	151	0	154	0	160	0
—— of the keel for tonnage					122	0	123	2	122	0	125	5	131	4
Breadth extreme	39	8			41	0	41	6	43	5	44	0	45	0
Depth in hold	17	0			17	4	17	4	17	9	18	11	19	4
Burthen in tons	1013				1069		1128		1224		1291		1414	
60 GUN SHIPS.														
Length on the gun-deck			144	0	144	0	144	0	144	0	147	0	150	0
—— of the keel for tonnage					119	0	117	7	116	4	119	9	123	0½
Breadth extreme			37	6	38	0	39	0	41	5	42	0	42	8
Depth in hold			15	8	15	8	16	5	16	11	18	1	18	6
Burthen in tons			900		914		951		1068		1123		1191	

	ESTABLISHMENT OF								PROPOSED IN				Establishment of 1745.	
	1677.		1691.		1706.		1719.		1733.		1741.			
	Feet.	Inch.	Feet.	Inch.	Feet.	Inch.	Feet.	Inch.	Feet.	Inch.	Feet.	Inch.	Feet.	Inch.
50 GUN SHIPS.														
Length on the gun-deck					130	0	134	0	134	0	140	0	144	0
—— of the keel for tonnage					108	0	109	8	108	3	113	9	117	8½
Breadth extreme					35	0	36	0	38	6	40	0	41	0
Depth in hold					14	0	15	2	15	9	17	2½	17	8
Burthen in tons					704		755		853		968		1052	
40 GUN SHIPS.														
Length on the gun-deck					118	0	124	0	124	0	126	0	133	0
—— of the keel for tonnage					97	6	101	8	100	3	102	6	108	10
Breadth extreme					32	0	33	2	35	8	36	0	37	6
Depth in hold					13	6	14	0	14	6	15	5½	16	0
Burthen in tons					531		594		678		706		814	
20 GUN SHIPS.														
Length on the gun-deck							106	0	106	0	112	0	113	0
—— of the keel for tonnage							87	9	85	8	91	6	93	4
Breadth extreme							28	4	30		32	0	32	0
Depth in hold							9	2	9		11	0	11	0
Burthen in tons							374		429		498		508	

The dimensions of the establishment of 1745, in this Table, which are the last, were determined from the proposals which the Lords Commissioners of the Admiralty directed the flag-officers, the Surveyor of the navy, and the Master Shipwrights of the dockyards, after consultation, to lay before them, of a scheme of dimensions and scantlings, and a draught of a ship of each class; to remedy the defects which English ships were said to possess, of being weak from a deficiency in the scantlings, of not being able to carry so great a weight of metal as foreign ships, of their lower guns being too near the water, and of their being crank.[1] The ships built according to these proposals, it is said, carried their guns well, and possessed sufficient stability, but were formed too full in their after bodies,—a defect which was removed in the ships built at the commencement of the war in 1756, when a further increase of dimensions was also made. The improvement in the ships built according to the established dimensions of 1745, does not appear to have proceeded from any alteration in the *relative* proportion of the dimensions of the preceding establishments in 1719, 1733, and 1741. The length of the ships of the first class on the gun-deck, in the order of these four dates, appears to have been 3.48, 3.48, 3.5, and 3.49 times the extreme breadth; where very little difference exists in the relative dimensions. The improvement in these ships arose from the general increase of the dimensions, by which the guns were raised further above the water, (even supposing their height from the keel to remain the same,) in consequence of the load-water-line being lowered, the displacement being increased only by the additional weight of the hull, other weights remaining the same; the stability being also increased, the ships would incline less under the same press of canvass.

The progressive increase of the general dimensions of the different classes of English ships is shown in this Table. The greatest increase appears to be in the establishment of 1745 from that of 1741.

Spain was the first nation which increased the size of the different classes of their ships to a considerable extent; and

[1] Derrick's Memoirs of the Royal Navy, pages 136 and 145.

France followed her example, but with better success. The capture of the Princessa, soon after the commencement of hostilities with Spain in 1739, carrying 70 guns, and being upwards of 1700 tons burden, pointed out the propriety of increasing the dimensions of our largest class of two-decked ships, seen by the Table to be so much inferior to her. The large two-decked ships of the French were also proved to be very powerful and fine vessels, and in many points superior to the English eighty-gun ships with three decks. In several instances, ships captured by the French were found, when retaken by the English, to have had their force reduced from that they carried in our service. The Admiralty consequently directed the eighty-gun ships then in use, with three decks, to be substituted by two-decked ships, of 74 guns, whose dimensions were to be particularly considered, and care taken that their lower tier of guns should be six feet above the water.

Comparative Dimensions of Three Ships of different Nations, about the Middle of the Eighteenth Century.

	Length on the gun-deck		Extreme Breadth.		Burden in Tons.	Length in proportion to the Breadth.
	Feet.	In.	Feet.	In.	No.	
SHREWSBURY, English Ship of 74 guns, launched in 1750.	166	1	47	1	1594	3,52
MAGNANIME, of 84 guns, captured from the French in 1747.	173	7	49	7½	1832	3,49
PRINCESSA, of 70 guns, captured from the Spaniards about 1740.	165	1	49	8	1709	3,32

The increase of dimensions, in the English ships of 74 guns, proceeded very slowly, and, with the exception of the Triumph and Valiant, said to have been constructed after the Invincible, taken by Lord Anson from the French in 1747, whose length was 171 ft. 3 in., extreme breadth 49 ft. 9 in., and burden 1825 tons. The dimensions of these ships appear to have been generally confined to 168 ft. 3 in. in length, 47 ft. 4 in. in breadth, and 1644 tons burden.

Though England did not possess any two-decked ships carrying 84 guns till after the middle of the eighteenth century, the French and Spanish navies were long inferior to the English in their want of three-deckers, of which experience taught them the largest classes were much too powerful for their largest two-deckers. It was not till after the peace in 1763, that either France or Spain possessed a single ship of three decks. The Royal George, a three-decker carrying 100 guns, launched in 1756, of 2046 tons burden, was built of superior dimensions to our preceding first-rates, and commenced the increase of size, which has been so successfully carried forward in modern ships.

The following table shows the magnitude and relative dimensions of the principal classes of modern ships of several European nations. The length and breadth would have been taken at the load-water section, if they could have been obtained for all the ships. There will be, however, no considerable error in comparing them according to the dimensions given in the table.

Comparative Dimensions of Modern Ships of different Nations.

NAMES of SHIPS.	Number of Guns.	Length on the gun-deck of the Line of Battle Ships, and on the lower deck of the Frigates.	Extreme Breadth.	Burden, in Tons.	Proportion of the Breadth to the Length.
		Feet. In.	Feet. In.	No.	
Spanish.					
San Josef	110	194 3	54 3	2457	$\frac{100}{358}$
San Nicolas	82	179 9½	49 7¼	1942	$\frac{100}{362}$
San Antonio	74	174 10	47 10	1700	$\frac{100}{365}$
Medea, frigate	44	147 2	40 1	1046	$\frac{100}{367}$
French.					
Commerce de Marseilles	120	208 4	54 9½	2747	$\frac{100}{380}$
Tonnant..........	84	194 2	51 9¼	2281	$\frac{100}{375}$
Bahama	74	175 7	48 0	1772	$\frac{100}{365}$
Niobe, frigate	44	156 0	40 8½	1142	$\frac{100}{383}$
Unité, frigate	42	148 6	39 7	1040	$\frac{100}{375}$
Swedish.					
Taken from Chapman's large work on ships of war..	110	207 8	55 7⅜		$\frac{100}{372}$
——— ———	80	186 2¾	50 4¼		$\frac{100}{369}$
——— ———	74	179 3½	49 0⅜		$\frac{100}{365}$
——— frigate..	40	151 1½	39 10⅜		$\frac{100}{379}$
Danish.					
Christian VII......	84	187 0	50 10½	2131	$\frac{100}{367}$
Princess Carolina..	74	173 1½	46 3⅜	1637	$\frac{100}{373}$
Freya, frigate	42	148 7	39 4	1022	$\frac{100}{377}$
English.					
Caledonia	120	205 0	53 6	2602	$\frac{100}{383}$
Ganges	84	193 10	51 5¼	2255	$\frac{100}{376}$
Bulwark..........	76	176 2½	48 9	1836	$\frac{100}{361}$
Portland, frigate...	60	172 0	43 8	1468	$\frac{100}{393}$
Latona, frigate	46	150 1½	39 11	1063	$\frac{100}{378}$

From this Table it appears that the general dimensions of English ships are not inferior to those of other nations. Our first-rate is but a little below the French first-rate in this Table, which is of larger dimensions than most of the three-deckers of that nation. The San Josef, the largest Spanish ship taken during the war, is less than our first-rates. This ship, although of inferior dimensions to the Santissima Trinidada, was of equal magnitude with the general class of Spanish three-deckers. The Swedish ship of 110, proposed by Chapman, is the largest ship in the Table. In the other classes, the magnitude of the English ships is rather superior, on the average, to those of other nations.

The advantage of giving large dimensions to ships carrying a certain force, arises from several causes. It enables them to possess great stability, and thereby to carry a great press of sail, with a comparatively small body immersed in the water: thus giving them a great moving force in proportion to the resistance they experience in moving through the water, which must increase their rate of sailing. Large dimensions in proportion to the number of guns, gives fine quarters to the men in action. It also enables a finer form to be given to ships below the water, so that they may have a good entrance forward, and a clean run aft to the rudder; and to have the form best calculated to present great lateral resistance to the water, which prevents the ship from making much lee-way. This form below the water, in connexion with great stability, is very beneficial in enabling the ship to beat off a lee-shore.

The greater expense arising from the increase of dimensions is, however, a disadvantage which renders it desirable not to carry this principle far beyond necessary limits. The number and weight of guns a ship is intended to carry, must be the foundation of the design. The total weight of a ship being found, a corresponding displacement must be given, and the height of the lower tier of guns, when the ship is fully stored and provisioned, fixed at not much less than six feet from the water's surface. The number of guns to be placed on a deck being determined, with such a distance between them as naval officers have found to be sufficient to work the guns conveniently in action, and the necessary length given before the foremost

and abaft the aftermost port, the least length which can be given to the ship is found. The breadth in proportion to the length must then be determined, so that the stability may be sufficient to work the leeward guns in a strong wind. The draught of water being then determined, such as experience has found to be necessary to keep a ship of such a class up to the wind, the form of the body may be given according to the judgment of the constructor, the best calculated for producing the necessary qualities of velocity, lateral resistance, answering the rudder readily, &c. Should the total displacement be then found equal to the weight of the ship, the dimensions are determined according to the necessary limits. Whatever increase of dimensions beyond these limits may be given, to alter any particular property, must be at the disadvantage of additional expense.

From these Tables also may be seen, the relative proportion between the length and breadth of ships of different nations. The determination of the breadth to be given to any ship of which the length is fixed, is one of the most important considerations in the design. It is this dimension which principally affects the stability of ships,—a quality on which the efficiency of a man-of-war, as well as its safety, depend. Although in order to determine the true value of the moment of stability, it is necessary to find the correct volumes of the parts immersed and emerged by the inclination, yet the breadth being the principal element in the determination of the value of this property, a tolerably correct judgment of the relative stability of ships, if not very dissimilar in form, may be generally obtained by comparing their relative breadths. This property, *ceteris paribus*, is proportional to the length and third power of the breadth; so that a very small addition to the breadth increases the stability as much as a very considerable addition to the length. The advocates for great length in proportion to the breadth of ships, assert that long and narrow ships are the fastest sailers. With the same moving power, that is, with the same quantity of sail, the long and narrow ship, under some circumstances, particularly with the wind aft or but little on the quarter, in light breezes and a smooth sea, may sail faster than a broader and shorter ship. But when a ship sails with the wind at any point between the limits of being

close-hauled and on the quarter, the ship is necessarily inclined by the power of the wind on the sails, and requires sufficient stability to prevent the inclination becoming too great. A deficiency in stability is frequently of the most serious consequence: it may cause the loss of a ship on a lee-shore; it may prevent a ship in a stiff breeze, when engaged with an enemy, from using the leeward guns; in a chase it may render a ship incapable of carrying the necessary press of sail to come up with the enemy; by a ship heeling much, it brings the round part of the body into the water, and the keel and lower parts of the body, which oppose the greatest lateral resistance to the water, become more oblique to its direction, and the ship is consequently allowed to fall to leeward more than it would if less inclined; the effect of the force of the wind on the sails is also diminished by its direction being more oblique when the ship is inclined. The importance of a ship possessing great breadth in proportion to the length, to ensure sufficient stability, appears under these circumstances much more than to counterbalance the advantage, which, by having greater length in proportion to the breadth, might be obtained in velocity in light winds and a smooth sea. It may be observed, that too great stability is, on the other hand, dangerous by the great strain it brings on the ship, and the liability it gives of carrying away the masts. But this is an excess, which is very rarely complained of; the more frequent defect appears to be, a deficiency in this quality.

In the last column of this Table is shown the breadth of the different ships in proportion to their length. In the ships of three decks, the relative breadth of the ships of the different nations is in the following proportion and order: of the Spanish ship $\frac{100}{358}$, of the Swedish $\frac{100}{372}$, of the French $\frac{100}{380}$, and of the English $\frac{100}{383}$; where the relative breadth of the Spanish ship is seen to be the greatest, and of the English ship the least. In the large class of ships of two decks, of 80 guns and upwards, the relative breadth is in the following proportion and order: of the Spanish ship $\frac{100}{362}$, of the Danish $\frac{100}{367}$, of the Swedish $\frac{100}{369}$, of the French $\frac{100}{375}$, and of the English $\frac{100}{376}$; where the relative breadth of the Spanish ship is seen to be the greatest, and of the English ship the least. The difference, however, in the relative breadth of the last two, the French and English ships,

is very little, and if some other French eighty-fours had been taken instead of the Tonnant, the relative breadth of the French and English ships of this class would have been the same, the Ganges having been built after a French ship, the Canopus. In the smaller ships of two decks, the relative breadth is in the following proportion and order: of the English $\frac{100}{361}$, of the Spanish, Swedish, and French $\frac{100}{365}$, and of the Danish $\frac{100}{373}$; where the relative breadth of the English ships is the greatest, and of the Danish the least. In the frigates, the relative breadth is in the following proportion and order: of the Spanish ship $\frac{100}{367}$, of the French Unité (while in the French service, the Imperieuse) $\frac{100}{375}$, of the English Latona (one of a numerous class in our service, built after the old Leda) $\frac{100}{376}$, of the Danish $\frac{100}{377}$, of the Swedish $\frac{100}{379}$, of the French Niobe $\frac{100}{383}$, and of the English Portland $\frac{100}{393}$; where the relative breadth of the Spanish frigate is seen to be the greatest, and of the English 60-gun frigate the least. The relative breadth of the French frigates taken during the last war, is generally nearer that of the Niobe than of the Unité.

From this comparison, it appears that the relative breadth of our 120-gun ships is less than that of the three-decked ships of the other nations; that the relative breadth of our large class of two-decked ships agrees nearly with that of the French, and is less than that of the ships of the other nations; and that the relative breadth of the 60-gun frigates is considerably less than that of the frigates of other nations, and of most of our own frigates. The relative breadth of the Bulwark and Latona stands high in the order of the ships of their respective classes.

It does not appear, from this Table, that any regularity exists in the proportion between the length and breadth of ships according to their magnitude. Whether ships, as they increase in magnitude, should have greater or less relative breadth in proportion to their length, does not appear to have been attended to as a general principle in the design of the ships of the different nations. In the Spanish ships, the relative breadth of those of three decks is greater than that of the ships of two decks, and the relative breadth of the larger Spanish and Danish ships of two decks is greater than that of the smaller ships of two decks; and the relative breadth of the two-deckers is

greater than that of the frigates. In the ships of the other nations, the contrary is more frequently adopted, although very irregularly.

The first consideration respecting the relation between the length and breadth of ships of different magnitude, is, whether large or small ships require the greater relative stability. Now suppose a larger and smaller ship to have their moments of sails in proportion to their stability, and the height of their lower tier of guns to be the same from the water's surface, when they are upright; while these two ships would then be inclined, by the force of the wind on the sails, to the same angle, this inclination might be dangerous to the larger ship, but quite safe to the smaller ship, the sides of the two ships above the water being immersed nearly in proportion to their breadths. Supposing the breadth of the larger ship to be 50 feet, and of the smaller 40 feet, and the height of the lower ports in both ships to be 6 feet from the water's surface, when the lower ports of the smaller ship are, in consequence of the inclination, two feet from the water, the lower ports of the larger ship are only one foot from the water.

Supposing that the moment of sails is given in a proper proportion in the smaller ship, a smaller moment of sails in proportion to their relative stability must either be given to the larger ship, or a greater moment of stability, retaining the same moment of sails. For the sake of velocity, it is desirable that the stability of the larger ship should be increased.

Suppose the two ships to be similar, the one carrying two tiers of guns, the other three. The stability being in the proportion of the fourth power of the simple dimensions, if the centres of gravity of the two ships were raised above the centres of gravity of the displacements only in proportion to the dimensions of the ships, the stability of the larger ship would be increased in a much greater proportion than in the smaller ship; but as the centre of gravity in the large ship is raised by the additional deck and tier of guns higher than in the proportion of the dimensions, the stability is increased in one way and diminished in another. The effect of these elements of the stability on the value of its moment should be correctly ascertained. Probably, on the whole, the stability of the larger

ship may generally be rather increased than diminished by the alterations, but not sufficiently without a little increase of relative breadth. This, however, could be obtained by calculation and experiment, for the different classes of ships, and would be valuable information for the determination of the relative dimensions of ships of different sizes.

By comparing the dimensions in this Table with those of the three ships in page 245, it appears that the breadth of ships in proportion to their length is less in this Table than in those which were built about the middle of the last century. The relative breadth of the Spanish ship appears to have been then, as well as at later periods, the greatest in proportion to the length; the relative breadth of the English ship in proportion to the length appears to have been considerably less than that of the Spanish, and a little greater than that of the French ship. By the Table (page 241) it appears that the relative breadth of English ships in proportion to their length was increased in the establishment of 1706 from the dimensions of preceding establishments, and that this relative increase continued with very little alteration till 1745. Towards the end of the last century a decrease of their relative breadth was introduced, which has influenced most of the subsequent designs. The breadth of the largest ships, by the establishment of 1745, varied from $\frac{100}{349}$ to $\frac{100}{355}$ the length; at the present time, the breadth of most of our line of battle ships is within the limits of $\frac{100}{361}$ and $\frac{100}{383}$; by which it appears that the relative breadth of our line of battle ships is considerably less at present than it was at that period.

The proportional breadth which should be given to ships is very materially affected by the consideration of the number and weight of the guns which they are intended to carry; as the greater the number of guns, and the greater their weight, the more is the stability diminished by the greater elevation of the centre of gravity of the ship, which must be counteracted by a corresponding increase of breadth. The best disposition of force as to the calibre of the guns to be used on board different ships, is a very difficult subject, and particularly requires the opinion of experienced and scientific naval officers for its determination. It appears to be generally admitted, that the

effect of large shot is much more destructive than that of a greater number of smaller shot, making together the same weight. The limit to which the size of the guns on board ship may be carried with advantage, is bounded by the consideration of the number of hands required to work them, the convenience of handling the shot in action, the strain brought on the beams and ship's sides by their weight, and the effect they produce on the stability of a ship. The height of the guns above the water influences very materially the stability; and while particular attention should be paid, that the lower tier should be at a sufficient height to use the lee-ward guns under all circumstances in which they may be required, the upper tiers should be kept as low as possible.

The establishment of guns in 1757 and 1762, directed in the first-rates, 42-pounders on the lower deck, 24-pounders on the middle deck, and 12-pounders on the upper deck. The establishment of 1792, directed 32-pounders on the lower deck, 24-pounders on the middle deck, and 18-pounders on the upper deck. It appears that 42-pounders have been considered too heavy for use on board ship. The large line of battle ships of the Americans,[1] carry long 32-pounders on the lower deck, short 32-pounders on the upper deck, and 32-pounder carronades on the quarter deck, waist, and forecastle. The advantage proposed by this disposition of force, is the great weight of metal of a broadside, and the prevention of mistakes in the size of the shot in action. The principal force of large ships being chiefly required in general action, and at short distances, the short 32-pounders and the carronades are adopted as giving a very efficient force. The total weight of metal of a broadside of an English 120-gun ship is 1,520lb.; the weight of metal of one of these American two-decked ships, carrying guns in the waist, is 1,600lb. The English first-rate has thus the appearance of a greater force than it possesses, from the smallness of the weight of metal of many of the guns. To concentrate the weight of metal appears desirable, not

[1] The writer was on board one of these ships, the Washington, at New York, a few years ago, which carried 100 32-pounder guns and carronades: 32 long 32-pounders on the lower deck, 34 short 32-pounders on the upper deck, and 34 32-pounder carronades on the quarter-deck, waist, and forecastle. She had no roundhouse.

only as preventing incorrect comparison, but as giving the most efficient force, and as affording the means of keeping the weight of the guns low.

The most important consideration respecting any proposed disposition of guns, is to place the lower tier at such a height as to be at a sufficient distance from the load-water-line, and to give the ship such breadth as to ensure a proper moment of stability.

The advantage of dividing the ships of the Royal Navy into as few classes as the different services would admit, has been frequently recommended as very desirable, particularly as relates to the appropriation of stores and gear. Experience may eventually determine the classes, into which the Royal Navy might be advantageously divided. Such a division must, however, always be subject to alteration from previously unforeseen circumstances; such, for instance, as the adaptation of steam-vessels to the purposes of war, &c. Ships of three decks might probably be confined to one class, having a little greater breadth, and a little more height from the lower deck to the load-water-line than our present first rates. Ships of two decks may also probably be confined to one class, carrying 84 guns, as our present ships Ganges and Asia, with a little increase of breadth. Frigates might, perhaps, be confined to two classes, the larger carrying sixty guns, of about the same length as our present frigates of this class, and of a greater breadth; and the smaller class of forty-six guns, of nearly the same length and breadth as our present frigates of this force built after the Leda. The present twenty-eight gun frigates are generally considered a bad class, having too great height above the water in proportion to the part of the body below; the same defect which the old eighty-gun ships with three decks, and the sixty-four gun ships with two decks, possessed. This cannot be fully corrected without their dimensions being so considerably increased, as so render it questionable whether their expense might not be too great for their relative utility. A large class of corvettes, similar to some built in America, carrying twenty-four or twenty-six guns, might in many services substitute these small frigates, and be a powerful and useful ship in the service. Our corvettes of eighteen guns fully substitute the eighteen-gun brigs, found too large for their

rig, and are useful vessels for general service. The present ten-gun brigs, which are found good sea-boats, might be the last class. These seven classes, with cutters and other small craft, might probably constitute advantageously the Royal Navy.

There appear to be limits, beyond which the magnitude of the three great divisions of the navy into ships having one, two, or three decks, cannot be carried, without injuring their properties, and increasing the expense of construction, equipment, and wear and tear, to an extent incompatible with their respective force and general service. If a nation does not possess ships of each of these three divisions, of the greatest magnitude of the respective limits, which although not yet correctly defined, experience has advanced far towards approximating to, it may be surprised in wars with other nations, by having to oppose, with great inconvenience and additional expense, and perhaps ineffectually, the smaller ships with two decks to the largest ships of one deck, and ships with three decks to the largest ships with two decks. The large ships with two decks, of eighty-four guns, and the large frigates of sixty guns, may probably have arrived near the greatest limits of magnitude of these divisions, and therefore would prevent surprise by new classes of ships of other nations.

When the dimensions and necessary displacement of a ship are determined, the next element to be attended to in the design is the area and form of the midship section. The importance of this element in influencing the resistance a ship meets with in its direct course, is admitted by all constructors. The general character of the form of a ship, may, to a considerable degree, be known by the area and form of the midship section, the displacement, and three principal dimensions.

M. Romme attached so much importance to this element, that he considered if the midship sections were similar and equal in two ships of the same length, and same stem and stern-post, the direct resistance would be the same, whatever form was given to their bodies forward and aft. His experiments on this subject are very interesting and important; and although differing in results from most other writers on the subject, demand particular respect from the attention with which he conducted them, and from the size of his models. Among other experiments, he had two bodies made, the one an exact model

of l' Illustre, a French seventy-four, on a scale of an inch to a foot, making the length of the model about fourteen feet, and its breadth three feet eight inches; the other model had the same midship section, the same length, stem, and stern-post, with the fore and after parts formed by straight lines drawn from the midship section to the stem and stern-post.

The Commissioners, M. M. le Chevalier de Borda, de Bory, and l' Abbé Bossut, who examined the account of the experiments of M. Romme, and made a report on them to the French Academy, speaking on these two models, gave the following account of the experiments made on them: "M. Romme a comparé les resistances de ces deux modeles, à differens tirans d'eau. Il faisoit ces experiences dans un canal de 40 pieds de largeur et de 7 à 8 pieds de profondeur. De chaque côté du canal on avoit placé deux piquets à 75 pieds l'un de l'autre, dont le premier etoit a 60 pieds du point de depart, afin que les corps eussent le temps de parvenir à une vitesse uniforme avant l' observation. Ces piquets etoient garnis de pinnulles au moyen desquelles on observoit l' instant on les corps passoient par le travers de ces piquets. Un compteur à secondes servoit à determiner le temps quils employoient à parcourir les 75 pieds. Enfin, chaque experience etoit répetée plusieurs fois, et on prenoit un resultat moyen pour obtenir plus de precision. Le resultat de ces premieres experiences a été que les deux modeles à tirant d' eau egal, et mus par les memes poids, ont toujours eprouvé la meme resistance. M. R. a encore trouvé qu'en tirant successivement, d'abord par l' etrave et ensuite par l' etambot, celui des deux modeles dont la surface etoit formée par les lignes droites, la resistance etoit la meme. Enfin, ayant coupé les deux modeles en deux parties egales, et ayant joint l' avant du premier modele avec l' arriere du second, et l' avant du second avec l' arriere du premier, les deux corps ont toujours parcouru leur espace de 75 pieds dans le meme nombre de secondes, soit que le mouvement se fit par l' etrave ou par l' etambot."

They proceed to mention three objections to the results of these experiments. The first is, the shortness of the time the models were in motion, being with the smallest velocity only 27″, and with greatest velocities only 15″, 14″, and even 13″. The second objection is, that from the great difference of form

of these two bodies, the one being probably too sharp, and the other too full, the resistance they experienced might vary equally from that of some intermediate form. The last objection they mention, which they consider the most important, is the apparent disagreement between the results of these experiments and the effect produced on ships at sea in their velocity, by increasing or diminishing the difference of their draught of water forward and abaft. In examining these objections, they show what may be advanced on the other side of the question in favour of M. Romme's experiments; and on the last objection make the following very excellent remarks:—that not any one of the theories of the resistance of fluids explains this effect, and that by calculating according to any of them the change which would be produced by a small variation in the difference of draught of water forward and aft, the alteration would be extremely small, so as not in any tolerable degree to account for the fact, which they therefore consider may not arise from the difference of draught of water influencing the resistance; but that, probably, from the inclination of the masts being altered, by which the sails take a different position in relation to the wind, they may be set more or less advantageously; or that the sails forward and aft being better balanced, and forming an equilibrium with the resultant of the force of the water on the bottom, there may be no necessity for keeping the ship in its direction, by means of the rudder, which always retards the sailing.

They finish their report by observing, "Nous concluons de l' examen que nous venons de faire des expériences de M. R., que s'il n'est pas exactement vrai que la forme des proues des vaisseaux n' influe pas beaucoup sur la resistance qu'ils éprouvent, par le choc de l' eau, du moins il est très-probable que les proues peuvent beaucoup varier, le maitre couple restant toujours le même, sans que la resistance eprouve des changemens sensibles."

The results of these experiments being very different from the results of experiments, made by others on the resistance bodies experience moving in the water, although adding to our information on the subject, are far from setting the question at rest. The writers of the report mention, as agreeing with the results of M. Romme's experiments, the result of the experiments

made by Chapman on one of the bodies he used in his experiments on resistances:—No. 4, in his series, one end of which body was conical, and the other parabolic, in which the resistance was (nearly) the same, whether the body was moved with one or the other end foremost. It should however be remembered, that this was only one of seven models of different forms which Chapman used in his experiments; and, it may be observed, was the case in which the greatest section was in the middle of the length of the body. In the experiments on the six other models, the results were in some cases very different; and in one case of the experiments on No. 6 in his Table, in which the body was composed of two conical ends, with the greatest section one-fourth the length from one end, the time of the body's moving through 74 feet was $12\frac{1}{2}''$, when the obtuse end was foremost, and $17\frac{1}{2}''$ when the acute end was foremost. As far, therefore, as Chapman's experiments are to be compared with M. Romme's, the results must be considered very different.

On the whole it appears fair to conclude, that, though the midship section may not be taken so exclusively as M. Romme considers, as the element which determines the direct resistance, yet that this section is of the greatest importance in estimating the velocity of a ship in its direct course. It may generally be adopted with safety in comparing the direct resistance of two ships of the same length, not varying extremely in the form of the fore and after bodies. Where the difference of draught of water is considerable, the projection of the part of the body and keel, that may be below the midship section, should be added to the area of the midship sections in the comparison. This comparison will certainly lead to no bad consequences, if strictly confined to the subject of direct resistance; but it must be at the same time remembered, that two ships, with the same midship sections and length, may possess different stability, by the one retaining its extreme breadth much further before and abaft this section than the other, and by being much fuller than the other at the water-line forward and abaft; so that these two ships in an oblique course may move with different velocities, the moving power of wind on the sails being in proportion to their stability.

The midship sections of two ships may also be exactly the same, but by the variation of their fore and after bodies, their qualities of pitching and 'scending, rolling, steering, &c. may be very different.

The best form for the midship sections of ships is yet undetermined: local circumstances in many instances, and the peculiarity of service in others, frequently direct the necessary form; but where constructors are not limited by these considerations, they frequently differ very widely in the forms they recommend for this element of design. Great difference of form may however exist, while the designs may still possess all the essential qualities of good ships. Sufficient displacement, with a proper height of ports above the water, stability in a good proportion, and well regulated at different inclinations, sailing fast, answering the rudder readily, being weatherly, &c., are qualities which may be possessed in an eminent manner by ships having very different midship sections. The same results may frequently be obtained by different arrangements: for instance, the stability of a ship may be increased from an original design defective in this quality, either by lowering the centre of gravity, by increasing the breadth of the ship at the water-line, or by retaining the same breadth at the water-line, and filling the parts immediately above or below it, within the limits of the inclination. The best method of increasing this quality in any particular instance must depend on the peculiarity of the design, and the extent to which the different elements may have been carried in the design. Constructors may also attach a greater or less degree of importance to different secondary qualities, or may prefer increasing one quality, although it may be at the expense of another, by which the forms will necessarily vary according to the knowledge and judgment of the constructor.

The form and area of the midship section, of which the fore and after bodies partake for a considerable distance forward and abaft, will however give a tolerably just character of a ship's form as respects many important qualities: the direct and lateral resistance, the extreme breadth and mean draught of water, the form of the body between the limits of the immersion and emersion, caused by the ship's transverse inclina-

tion, the rising of the floor, and the tumbling-home of the top-sides.

The character of the three forms generally given to the midship sections of line of battle ships are shown in Fig. 22, 23, and 24. Fig. 22 shows the form of many old English ships of the line in the last century; Fig. 23 shows the form of most of the French ships of the line; and Fig. 24, the form of the Swedish ships of the line. Most of our present English ships of the line partake considerably of the French form in Fig. 23.

The peculiarity of the form of Fig. 22, is the rotundity of the part of the body below the water's surface, a form calculated to produce but little lateral resistance when the ship is moving in an oblique course, by which its falling to leeward will be not sufficiently opposed. This rotundity will also present but little resistance to rolling, which however may be checked by it less suddenly than by a more irregular form. In other respects the general properties of this form differ but little from those of Fig. 23, which will be best seen by comparing them with the properties of Fig. 24.

The principal difference of form in the midship sections of the French and Swedish ships of the line, is the flatness of the French and the rising of the Swedish floors. This difference in the rising of the floors affects several properties. Supposing the areas of Fig. 23 and 24 to be equal, the centre of gravity of Fig. 23 is lower than that of Fig. 24, and by estimating the direct resistance of these two planes, according to some of the best theories of the resistance of fluids, in which the depth below the surface of the water is one of the elements, the resistance of Fig. 23 is greater than that of Fig. 24. It appears that the established principle of fluids pressing in proportion to their depth below their surface, must necessarily enter into the investigation of every theory of the resistance of fluids, which embraces all the circumstances connected with it. The objection, that it is useless to introduce it into the investigation, because it enters into the expression giving the value of the resistance on the after part of the body, as well as into the expression representing the value of the resistance on the forepart of the body, the difference of which two expressions gives the true value of the total resistance, is certainly erroneous,

because these two expressions may not be influenced by it in the same proportion, the mean depth of the after-part of the body being generally different from that of the fore-part of the body, and the resulting expression giving the total resistance, still retaining this element. In the theory of Don George Juan, this element is connected with the whole of the investigation, and is retained in the final results. This consideration gives the advantage in respect to the direct resistance to the Swedish form of the midship section.

Another consideration connected with the comparison of the flat and rising floors, is the alteration in the stability occasioned by this difference of form. The extreme breadth and area of these two sections are in all these cases supposed equal. In the first place, supposing the transfer of the part of the displacement in the vicinity of the flat floor to be made below the part of the body immersed by the inclination at which the stability is to be estimated, the stability of the ship with the flat floor will be greater than of the ship with the rising floor, in consequence of part of the ballast and of the moveable lading being stowed lower. In this case the stability of the ship with the flat floor is greater than that of the ship with the rising floor, in proportion to the excess of the moment of the moveable part of the ballast and lading, multiplied into the distance their common centre of gravity is lowered, above the moment of the variable part of the displacement multiplied into the distance its centre of gravity is lowered. At very small inclinations, the parts of the bodies of Figures 23 and 24, within the limits of the immersion by the inclination, will vary very little; at five degrees there is no sensible difference. At this small angle of inclination the stability, by calculation, of the ship of which Fig. 23 represents the midship section, is greater than that of the ship of which Fig. 24 represents the midship, by about $\frac{1}{300}$ the whole moment of stability. This very trifling increase of stability is the most favourable case in which the flat-floored ship can be viewed with respect to the stability. At greater angles of inclination, the stability of the ship with the rising floor is increased by the transfer of the part of the displacement within the limits of the immersion, in a much greater proportion than it is diminished by the part of the

moveable ballast and lading being higher than in the flat-floored ship. At an inclination of 12 degrees, the stability of the ship, of which Fig. 24 represents the midship section, is greater than that, of which Fig. 23 represents the midship section, by the greater fulness of the part immersed by the inclination, by about $\frac{1}{30}$ the whole moment of stability, while its diminution by the rising of the weights is only $\frac{1}{300}$ the moment of stability; leaving on the whole an increase of $\frac{1}{60}$ the moment of stability in the ship with the rising floor. At an inclination of 20 degrees, the increase of the stability of the ship with the rising floor is still much greater: the increase of stability by the augmentation of the part within the limits of the immersion by the inclination is about $\frac{1}{17}$ the whole moment of stability, while the diminution of stability by the rising of the weights is as before $\frac{1}{300}$ the moment of stability; leaving on the whole an increase of nearly $\frac{1}{18}$ the whole moment of stability in the ship, of which Fig. 24 represents the midship section. On the whole, it appears, that the form of the ship with the rising floor is much more conducive to an increase of stability than the ship with the flat floor, from the transfer of the part of the displacement to the vicinity of the water-line.[1]

Another consideration connected with the flat and rising floors, is the lateral resistance, which a ship meets with, sailing in an oblique course, which opposes falling to leeward. To determine correctly the relative lateral resistance, caused by this difference of form, it would be necessary to enter into very tedious calculations on two ships of the same length, breadth, draught of water, and displacement, but differing in form as to the flatness or rising of the floors. The lateral resistance of the flat-floored ship is probably greater than that of the ship with the rising floor, as far as relates to the bodies of the ships,

[1] See the notes of M. Clairbois and Dr. Inman in the English translation of Chapman's Treatise on Ship-building, page 237 to 243. The attempt of M. Clairbois to prove that the flat floor conduces to the stability of a ship, is clearly shown by Dr. Inman to completely fail at large angles of inclination. The error in the investigation of M. Clairbois is shown to arise from taking the height of the metacentre as a measure of the stability at large angles of inclination.

independent of the keel; but as the lateral resistance on the keel forms a considerable part of the whole lateral resistance on the ships, this must be particularly attended to. Suppose the two ships sailing in an oblique course, to be inclined to any given angle, and let *a b c*, Figs. 23 and 24, be drawn touching the floors, and parallel to the water-line on the ship when inclined; then the lateral horizontal resistance is in the direction *a b c*, which in Fig. 23 passes near the lower part of the keel, and in Fig. 24 passes rather above the upper part of it, so that the water is prevented from acting freely on the keel in the ship with the flat floor, by the builge of the floor intercepting it in its passage, while in the ship with the rising floor the keel receives freely the whole force of the water. This increase of resistance on the ship with the rising floor, arising from the difference of the action of the water on the keel, is probably fully equivalent to the excess of the lateral resistance on the body of the ship with the flat floor, above that on the body of the ship with the rising floor, independent of the keel. The lateral resistance on the whole, in ships with rising and flat floors, may be considered generally nearly the same; but in cases where the floor is very flat, and extends far forward and aft, it is probable that the lateral resistance is in favour of the ship with the rising floor.

With respect to steering well: ships with either a rising or a flat floor, with a proper adjustment of body and a right disposition of sails, may answer the helm well. It may, however, be observed, that if a ship has a very flat floor extending far aft, the current of water passing along the ship's bottom, may, by the sudden collapsing of the lower horizontal lines, be broken, and may probably not act so forcibly on the rudder, as if the current had passed along a surface not having any sudden curvature, as is generally the case in ships with a rising floor. This consideration may not, however, probably be of any great importance with respect to this property.

The rolling of the ship with the flat floor is probably not so regular as that of the ship with the rising floor, from the variation of the resistance being less uniform at the different angles of inclination.

The ship with the flat floor is the best adapted for lying aground; but this circumstance can have but little influence on the forms of English ships of war.

The two forms should also be compared with respect to the facility of obtaining the timbers of the frame; the curvature being more sudden in the ship with the flat floor, gives the advantage in this respect to the ship with the rising floor.

There may be some other qualities by which these forms may be compared, but the preceding are the most important.

On the whole it appears, as far as the general reasoning of the preceding remarks is correct, that the rising floor recommended by Chapman, and adopted in the Swedish ships of the line, is preferable to the flat floor generally adopted in the French ships of the line.

The adoption of the Swedish rising floor instead of the French flat floor, and an increase of breadth in proportion to the length, might probably be attended with very considerable advantage in the ships of the Royal Navy of England.

M.

ART. XXXI.—*An Account of the Methods which have been resorted to in order to prevent the Depredation of Sea Worms on Ligneous Substances: by* JOHN KNOWLES, ESQ., F.R.S., *of the Navy-Office.*

THE account given by Mr. Willcox, in the last Number of 'Papers connected with Naval Science,' of the ravages made on ships by sea-worms, naturally leads to the consideration of the means which have at various times been adopted to prevent the dangers, not only which ships are subjected to from these destructive animals, but also works of civil architecture, from their destroying the wooden piles driven for their support. Embankments made of wood, to prevent the encroachment of the sea, suffer considerably from worms, and our neighbours, the Dutch, have expended large sums annually in repairing their dikes, on which the safety of their country depends, in consequence of the injury which the wood has sustained from these animals.

As there are no official records of the early period of our naval history, we are indebted to accidental circumstances for a knowledge of the operations of our ancestors, but from these we can form a safer judgment than from documentary evidence, for they not only show the methods practised, but also how far they have been successful.

The method in practice to prevent injury to the ships' bottoms from worms, at the time England first possessed a navy, in the reign of Henry VIII., was that of covering the immersed part with the loose animal hair which is separated from the skins in the first process of tanning; the vehicle used for attaching it to the ships' bottoms was pitch, or a mixture of tar and pitch; this was then covered with a sheathing board, of about an inch in thickness, to keep the hair in its place.

In the early part of the reign of Elizabeth, it was determined that a naval arsenal should be formed at Sheerness; and in order to carry an important point,—that of having the facing of the wharf in deep water, such ships were sunk, to form a foundation, as were from age rendered useless for the purposes of war. It may fairly be presumed that these ships were built in some preceding reign, and probably in that of Henry VIII. The recent improvements which have taken place in the naval arsenal at that port, and the consequent removal of the remains of these ships, have put us in possession of their state. It was found that their bottoms had been covered thickly with hair, that much of the wood was decomposed,—some petrified; but the hair was apparently in as perfect a state as when first used.

The same results, with respect to the state of the hair, were found in the Josiah, built in 1694 and sunk in 1715, at Sheerness; and in the Golden Horse, frigate, sunk at Chatham in 1688, and recently removed; the hair used for caulking some of the seams was in an equally good state, while there were no remains of the oakum used for the same purpose. These are sufficient to prove the almost insolubility of animal hair; and there are numberless instances on record of the perfect preservation of ships' bottoms from worms when covered with this substance.

Notwithstanding this preservative, it became an object to

protect the sheathing board, and also the bottoms of such new ships as were not sheathed, as well as to cleanse the bottoms of such ships as had been to sea, from the animal and vegetable matter that adhered to them. For this purpose it has been usual to have recourse to breeming, which was done by partially charring the wood by means of burning reeds, and then covering it with a mixture of some of these substances: tar, resin, tallow, soot, pulverized charcoal, brimstone, and many others which were either poisonous or noxious to the worms. With the former view, mundic has been tried. The preservative qualities of these were, however, of short continuance, for they were either washed off by being imperfectly soluble, or worn off by the friction of the water. Besides these disadvantages, masses of shell-fish or sea-weed accumulated on their bottoms, and impeded their sailing to such a degree, as to render it necessary to cleanse them every year. Charring the wood, and covering it with whale oil, is also a preservative for a time, but its efficacy is destroyed by the action of the water in a few years.

Tar appears to have been the vehicle generally used for placing the substances which we have named upon ships' bottoms; and although mineral tar must have been known in this country for nearly two centuries, yet there is good reason to believe that, until the year 1764, it was not tried upon the bottoms of ships. As coal tar is now generally preferred to vegetable tar, for the wood-work of ships, it may not be uninteresting to give a succinct account of the discovery and use of this article in England.

The prejudice which existed against the use of pit coal, in the early part of the seventeenth century, from the smoke which it emitted, led persons to endeavour to remedy that evil; and we find that a patent was granted, in the year 1627, to John Hackett and Octavius Strada, "for their invention of rendering coals as useful as wood for fuel, in houses, without hurting any thing by their smoke." It is evident that this invention was the making of coke; and in doing this, no doubt they obtained coal tar; but whether to any, or to what uses it was put, would be in vain now to inquire.

In the latter part of the seventeenth century, (1683,) Beecher,

the then most celebrated chemist of the north of Europe, states, that "he had succeeded in adapting to common purposes the inferior kinds of turf of Holland, and the inferior coal of England, and procured from them a tar superior to the Swedish; he had made it known in England, and shown it there to the King, who ordered a proof thereof to be made in his presence." He adds, "I have tried it both on timber and ropes, and it has been found excellent."

The next introduction of coal tar was by Admiral Sir Charles Knowles, who was a zealous officer in promoting the interests of the Navy, and indefatigable in carrying his views into execution; he recommended that the fossil tar, found in the coal-pits of the Marquis of Rockingham, near Sheffield, should be mixed with the scales arising from the forging of iron, and then placed on ships' bottoms. This proposition was carried into effect on several ships, about the year 1764, but the general use of copper plates for sheathing, which took place shortly after that period, did away with the necessity of this and other means for the protection of ships' bottoms from worms.

In 1780 Earl Dundonald obtained a patent for producing tar from coals; and in 1785 it was partially introduced for naval purposes, and found by a great variety of experiments to be in all cases at least equal, and in many cases superior, to vegetable tar: the expense, however, of manufacturing it was a bar to its more general use.

Since the practice of lighting cities or large towns with carburetted hydrogen gas, procured from sea-coal, has become almost universal, the quantity of mineral tar has been larger than the demand, consequently the price is low, and its use very general; it has been found an excellent preservative of wood, and, while it remains on the surface, a preventive from worms; but this, like other external applications, is subject to be displaced, and then the timber is left unprotected.

In the last Number of this Work, I drew the attention of the public to an invention of Mr. Bill, for rendering wood almost incorruptible and protecting it against worms; I mention it again in this place, because the specimens appear to be saturated with substances found in the coal tar. This discovery of Mr. Bill, will ere long, make a new era in Naval and Civil

Architecture; it will render every country independent of others for the supply of durable timber; for the wood which now decays almost as soon as it is felled, may be made thereby far more lasting than the most durable timber known. This is not merely speculative, for the specimens have been put during five years to the severest trials known without undergoing any change.

The protection afforded by metallic sheathing was tried at the end of the seventeenth century, for we find in the year 1670 that an Act of Parliament granted to Sir Philip Howard and Francis Watson, Esq., the sole use of the manufacture of milled lead [1] for sheathing ships. This was first put upon the Phoenix frigate in the year 1671, and between that period and 1690 the bottoms of twenty ships were so covered: the practice was then discontinued in consequence of the destruction of the rother irons and iron bolts, by their forming with the lead and sea water a simple galvanic circle. The sheathing of ships with metal appeared so feasible, that it was not confined to England, for the persons who proposed it had the address to introduce it into the navies of Spain and Portugal. The nails used for fastening the lead were of copper.

When the use of lead sheathing was discontinued in this country, very angry feelings were excited between the persons who manufactured it and the officers of government; the former insisting that it had answered every purpose, and the latter asserting that the fastenings of the ships were destroyed, and their sailing impeded by the adhesion of weeds to the metal. As it is always difficult after a lapse of years to ascertain with certainty the truth of such contradictory statements, the government determined to give lead another trial, and in 1768 the Marlborough, of 68 guns, was covered with it; in 1770 this ship was docked for examination, it was then found that the lead was covered with weeds, and that the iron fastenings were much injured, thus confirming the assertion (in

[1] According to Alberti, the Romans used lead for sheathing ships, for he says that the galley supposed to have belonged to the Emperor Trajan, which lay 1,300 years under water, had her bottom covered with lead which was fastened with copper nails.

1690) of the government officers. The sheeting was therefore after two years trial removed, and the ship sheathed with wood.

In 1693, a Mr. Bulteel invented a metallic sheathing, and inserted a notice of it in the Transactions of the Royal Society, (8 vol. 6192 page,) but as this was a mixed metal, in which lead bore a considerable proportion, it was subject to all the inconveniences which arose from the use of the simple metal.

In the year 1759, copper-sheets were first introduced and placed for trial upon the keels and stern-posts of some ships. The success which appeared to attend this experiment induced a trial on a larger scale, and in 1761 the bottom of the Alarm frigate, of 32 guns, was wholly covered with copper sheets; these were very thin, twelve ounces only to the foot square, and very ill secured to the bottoms with pure copper nails, which were driven into the laps of the sheets only, and not into any other parts. In 1763 the Alarm was docked for the purpose of examining the copper, when it was found that "the rother irons and iron fastenings of various kinds were much corroded, some of the copper sheets were off the bottom, and others eaten through." But, notwithstanding this result, which appeared unfavourable, the practice was further extended with thicker sheets more firmly secured, and in 1783 it became general throughout the navy, at which period copper bolts were substituted for those of iron.

The expense of copper has induced the trial of a mixture of cheaper metals, and we find that Mr. Donithorne obtained a patent in 1780 for a mixed metal, tin and zinc, in the proportions of 112 of the former to 10 of the latter. Sheets composed of these were put on the bottom of the Porpoise, store-ship, and found to be subject to all the inconveniences attendant on lead sheathing. Pure zinc has also been tried with the same results.

A covering of metallic oxide has also been put upon the bottoms of ships; this was effected by driving into them broad-headed nails, technically called filling nails, the heads of which were nearly in contact with each other, these by oxidation in a short time entirely covered the wood; but the irregularity of surface produced by this, and by the shell-fish which adhered

to it, impeded the sailing of the vessels, and hence the practice has been confined to some ships lying stationary in harbour, and to piles driven for wharfs.

As copper has been introduced into the naval service for 65 years, a variety of trials have been made for its preservation—chemically, by purifying or alloying it with other metals, combining more or less of carbon with it when in a state of fusion, or divesting it of all impurities—and mechanically, by hammering, cold or hot rolling, &c. Very different results have been obtained at different times with copper treated in the same way, and the oldest manufacturers are still of opinion, that a great degree of uncertainty prevails in producing copper sheets of the same quality at different periods. To show the uncertainty which prevails on this subject, the copper sheets put upon the bottom of the Tartar frigate were almost wasted to nothing during the short space of four years, although the ship was never out of Sheerness harbour. The underlaps of the sheets were the only perfect parts; these, on being carefully analysed by Mr. R. Phillips, were pronounced by him to be of the purest copper which ever came under his analysis. The two instances of the greatest durability of copper ever known, were upon the bottoms of the Batavia, Dutch ship of war, and upon the Commissioner's Yacht at Plymouth; the former was found coppered when captured in 1799, in 1823 she was taken to pieces, the copper sheathing was then quite perfect, and apparently little worn. This ship also lay in Sheerness harbour for many years. Some of the copper on being analysed was found to contain about $\frac{1}{150}$ part of tin. The yacht at Plymouth was coppered September 1796, and this sheathing was in excellent order when last examined, November 1823, and, on a piece being analysed, found to contain an alloy of about $\frac{1}{100}$ of zinc.

The principal wear and waste of the copper sheathing is from the external surface, but if the internal one be not protected from the action of sea-water upon it, corrosion will necessarily take place. When the sheets were first introduced, their internal surface was painted with white lead, and cartridge paper, also painted, put between them and the ship's bottom. As this was not found to answer the desired purpose,

tar was substituted for paint; but, after a variety of experiments, brown paper tarred, was found to be the best preservative, with the exception, however, of a recent discovery, that of a felt composed of animal hair manufactured into thin sheets and then tarred: this, by adhering firmly to the ships bottoms and to the copper, protects both from the sea-water.

In order to improve the quality of copper sheathing, the Navy Board consulted the Royal Society as to the most likely method of attaining that object, giving at the same time all the information which they were in possession of, with specimens of copper which had been the most or the least durable. It immediately occurred to the President, Sir Humphry Davy, Bart., that a discovery which he had made some time previously, that, "when two metals are in contact the more oxidable one becomes quickly oxidated, while the other remained without any change," might be applied to the object proposed, by placing bars of iron or zinc in contact with the copper under water, and thus rendering it electro-negative. After a variety of experiments, Sir Humphry determined that these bars should be of cast iron, and that their surface should bear the proportion of $\frac{1}{250}$ part of the surface of the copper exposed to the action of sea-water; these bars were divided into six parts, two of which were on the keel of the ship in midships, two on the bows, and two on the stern, about three feet under water. The application of these, as far as the philosophical fact went, was conclusive, as the copper suffered no waste. But inconveniences arose which could not be foreseen. As the copper did not oxidate, myriads of marine animals and weeds adhered to the metal, remained there harmless, and impeded the sailing of the ships; and in some cases there was such an incrustation of shell-fish that they could not be removed by the ordinary means, and they adhered so closely as to render it absolutely necessary to take off the copper from the ships bottoms. This plan has therefore been abandoned on sea-going ships, and is now confined to those lying up in harbours.

The use of cast iron protectors has developed some curious facts. After they had been for some months on the ships bottoms, it was found that a red oxide was formed on the outer surface, and under it, for some depth, a substance

resembling plumbago. This substance, from having sulphate of iron as one of its constituents, when laid upon any body which would inflame, caused spontaneous ignition. Similar results were obtained by Mr. F. Daniel in the year 1817, in endeavouring to ascertain the nature of cast iron, by solution in diluted muriatic acid, and they are detailed in the second volume of the Journal of the Royal Institution, for the year 1817.

But the question is, how are the bottoms of ships to be protected, if any part of the metallic sheathing be accidentally removed? In the first part of this paper the durability of animal hair has been proved, and its protecting the bottoms of ships verified. Within a few years this hair has been manufactured into sheets, by a process called felting; these have been used on many ships under wood sheathing, and have not only proved a perfect protection from worms when copper has been removed, but saved ships which, if they had not been covered with this substance, would have foundered.[1]

It is a singular circumstance, that the first vessel on which the patent felt was placed by the British government, was saved by it from shipwreck. The ship Dorothea, sent on the first voyage of discovery to the arctic regions, was crushed between two fields of ice; the shock was so tremendous, that several of the beams which support the decks were broken, and all on board expected the ship would founder, but to their surprise no leak was discovered; and hence it was thought that the beams were the only parts damaged. She arrived in England without leaking; but when taken into a dock, and stripped for the purpose of examining into her state, it was discovered that ninety-six of the timbers under water were broken, the plank of the bottom deranged, and that the ship had been saved by the felt. The use of this article has become very general in England, and it is being introduced into all maritime countries. Our active and intelligent neighbours, the French, are also beginning its use, as a manufactory for making it is already established at Nantz.

[1] The article in question is manufactured, under a patent right, by Messrs. George Borradaile and Co., of London.

ART. XXXII.—*The Dimensions and Calculated Elements of the Sapphire, of* 28 *guns.*

(*To the Editor of Papers on Naval Architecture.*)

SIR,—Some of the readers of your valuable Papers on Naval Architecture may possibly feel interested in the trial which is about to take place between the three new 28-gun frigates, as to their relative qualities in sailing and working. For the information of such persons, I send you the principal dimensions, &c., of the hull and rigging of H. M. S. Sapphire, constructed at the School of Naval Architecture in Portsmouth Dock-yard.

I am, Sir,

A FRIEND TO NAVAL ARCHITECTURE.

Portsmouth,
Nov. 23, 1826.

	Tons.
Builder's Tonnage	600
Whole Weight,—Channel Service, 275 Men, and 70 Tons of Ballast	760
	Feet.
Length on the Gun-deck	122.5
Breadth Extreme	33.8
Draught of Water forward	14.6
——— aft	15.6
Depth in Hold	8.4
	Square Feet.
Area of the Load-Water-Section	3621
Area of the greatest Transverse Section . . .	310
	Feet.
Distance of the Centre of Displacement before the Middle of the Load-Water-Line	1.95
Depth of ditto below the Load-Water-Line . .	4.43
Greatest Transverse Section before the Middle of the Load-Water-Line	8.4
	Cubic Feet.
Solid immersed at an inclination of 5°	1258
Solid emerged at ditto	1262
	Feet.
Centre of Solid immersed, before the Middle of the Load-Water-Line	0.3
Centre of Solid emerged before ditto . . .	0.5

		Tons.
Moment of Stability at an inclination of 5°	. .	461
——— ——— 10°	. .	847

	Feet.
Height of Metacentre above the Load-Water-Line, in inclining from the upright position . .	6.75

Dimensions of the Masts and Yards.

	MASTS.			YARDS.		
	Length.		*Diameter.*	*Length.*		*Diameter.*
	Ft.	In.	In.	Ft.	In.	In.
Main	79	8	$25\frac{3}{4}$	72	0	$16\frac{7}{8}$
Main-top . . .	48	9	15	55	0	$11\frac{5}{8}$
Main-top-gallant . .	24	0	$8\frac{3}{8}$	35	2	7
Fore	73	4	$23\frac{3}{4}$	64	1	$15\frac{3}{8}$
Fore-top . . .	43	7	15	49	2	$10\frac{5}{8}$
Fore-top-gallant . .	22	0	$7\frac{1}{2}$	31	4	$6\frac{3}{8}$
Mizen	61	6	$18\frac{1}{8}$			
Mizen-top . . .	36	0	$10\frac{1}{2}$	36	0	$6\frac{5}{8}$
Mizen-top-gallant . .	18	0	$6\frac{1}{4}$	25	0	$5\frac{1}{8}$
Bowsprit . . .	50	6	$24\frac{1}{4}$			
Jibboom . . .	36	0	$10\frac{3}{4}$			
Flying Jibboom . .	37	0	$5\frac{7}{8}$			
Driver Boom . . .	48	8	$9\frac{3}{4}$			
Gaff	35	2	$8\frac{1}{2}$			
Cross Jack Yard . .	55	0	$11\frac{5}{8}$			

Positions of the Masts.

	Feet.
Main-mast abaft the Middle of the Load-Water-Line . . .	8.6
Fore-mast before do.	45.4
Mizen-mast abaft do.	42.3

Rakes of the Masts.

	Inches.		Feet.
Main-mast . . .	5	in	12
Fore-mast	1	in	12
Mizen-mast . . .	10	in	12
Bowsprit Stive	4 ft. 6	in	12

Areas of Sails with their Moments, and Position of the Centre of Effort of the Sail.

	Area, in Square Feet.	Moment from the Load-Water-Line.	Moment from a Vertical Section at the Middle of Load-Water-Line.
Jib	1051.8	51119.9	+ 89196.9
Fore-course . . .	1890.4	62857.1	+ 87905.5
Fore-top-sail . . .	1835.8	127218.9	+ 86373.0
Fore-top-gallant-sail .	595.8	60175.8	+ 28181.3
Main-course . . .	2441.3	84225.5	− 20751.2
Main-top-sail . . .	2311.6	172444.6	− 20342.0
Main-top-gallant-sail .	753.1	82994.9	− 6891.1
Mizen-top-sail . .	1005.6	65163.5	− 45252.4
Mizen-top-gallant-sail .	387.0	34636.5	− 17802.0
Driver	1349.6	49462.1	− 87182.9
Height of Centre of above-mentioned Sails . . .			58.02 feet.
Distance of do. before Vertical Section at the Middle of the Load-Water-Line			6.86 "

Art. XXXIII.—*On the Position of the Centre of Effort of the Wind on the Sails in relation to the length of the Vessel, by* Lieutenant A. G. Carlsund, *of the Swedish Royal Naval Engineers.*

The placing the masts and sails in such a manner that the vessel shall continue its course steadily, with little aid from the rudder, is a problem so dependent on a perfect knowledge of the Laws of the Resistance of Fluids, that it cannot be solved in the present state of Hydrodynamical Science; and it even appears at present doubtful, if theoretical investigation will

ever alone fully elucidate the combined effects of wind and water, upon which the solution depends, in a manner which shall be applicable to the purposes of Naval Architecture. The only course to be followed at present, in order to obtain an approximate solution, seems therefore to be to consult experiment, and to deduce from it practical rules founded on correct principles. The great number of ships which are found to have their masts and sails correctly placed, will give sufficient data for a comparison of the effects of different forms of vessels upon the quality in question, and by application of the knowledge thus obtained, the placing the masts and sails may be brought to a degree of certainty, corresponding to the accuracy and discernment with which the observations and conclusions shall be made.

A consideration of the forces acting upon a vessel when in motion, will indicate in what manner experiment may be applied to the solution of the present question. We will suppose the vessel close hauled, as it is in this situation that an equilibrium between the effect of the wind on the sails and hull, and the resistance of the water, is most desirable. It will at first sight appear, that the lateral pressure of the wind on the sails and hull, and the effect of the rudder, should be in equilibrium with the lateral resistance of the water; this equilibrium being measured from the centre of gravity of the vessel, as it is through this point the axis of angular motion passes.

The centre of effort of the wind upon the sails and hull may be considered as situated in the common centre of gravity of the exposed surface, the sails being nearly parallel, and the forms of vessels above water differing very little, and as the curve formed in all sails by the force of the wind is nearly similar, its tendency to alter the position of the centre of effort need not be considered. As the action of the rudder should be small, when the sails are properly placed, it may also be omitted, and consequently the position of the common centre of gravity of the sails, and that part of the hull exposed to the wind, will be a point in the vertical line which should pass through the mean direction of the resistance of the water. In fact, if the two forces are equal, they must be directly opposed to each other, that the vessel may continue to move in a straight line.

By calculating the common centre of gravity of the projection of the hull above water, upon the longitudinal and vertical plane passing through the middle line, and of the sails exposed to the wind when the vessel is properly balanced, for vessels of different sizes and forms, and under different states of the sea, different velocities of the wind, and different inclinations; an idea may be formed of the influence of these causes in bringing the centre of effort of the water either forward or aft. It being always possible to get any vessel to continue its course steadily by a proper distribution of the sails, the true place for the centre of effort may always be found; consequently the proper situation for the masts can be determined after the vessel has been tried.

According to the experiments made by Chapman, the resistance a vessel experiences from the water may be considered as made up of the direct shock on all the parts which are opposed to the motion, and of the friction and adhesion of the water to the remaining parts. This manner of viewing the resistance agrees with the experiments made in this country by the Society for the Improvement of Naval Architecture, and also with those made in Sweden during the years 1811 and 1815 by the Society of Miners, in as far as that both these sets of experiments show, that the shape of the after-body has considerable influence on the resistance. If the motion is parallel to the longitudinal axis, the lateral pressure on one side will be equal and directly opposed to that on the other, and consequently their resultant vanishes, which is the case when a vessel is before the wind; but when she is close hauled, the lee-bow will experience a greater shock than the windward one, both in consequence of the greater angles of incidence and of the greater surface exposed to the shock. The gripe, keel, stern-post, and a considerable part of the side in midships, together with the lower and sharp part of the after-body, will all receive a shock on the lee-side; the remaining part of the after-body on the lee-side will make a less angle with the direction of the motion than that on the windward side, which, together with the keel, gripe, &c. on this side, will be influenced by the adhesion. This force or impediment to the motion on the windward side of the after-body diminishes the lateral pressure in that part,

and in a greater degree when the vessel is full aft than when it is lean. Chapman concluded from his experiments, that the adhesion on the after-body is a minimum when the angle of incidence is 13° 17′, and a frigate built in accordance with this supposition, but with a very full fore-body and great rake of stem, was found to be uncommonly ardent, though the masts were placed according to the common methods. This must have been in consequence of the diminished adhesion of the water to the after-body, as the shape of the fore-part would, according to the common theory, have had the contrary effect. It may not be improper to mention here, that the common notion that a full fore-body carries the mean resistance further aft is not true in general: it appears to be founded on the results obtained by Euler in calculating the place of the mean resistance in a parallelogram and a rhomboid,[1] but a little observation will show that the conclusion is fallacious. In fact, very different results would have been obtained if he had calculated forms approximating more to those generally used in Naval Architecture.

Experience confirms the truth of the reasoning before given; an addition to the gripe, for instance, makes the vessel more ardent; if the after-part of the keel or the stern were increased, it would lessen the ardency; it is in consequence of this that cutters with a great difference of draught of water require to have the centres of effort of the wind on their sails farther aft than when this difference is small, and that the ardency is diminished when the vessel is brought more by the stern, and increased when she is brought more by the head; but in these two latter cases the increased or diminished immersion of the bow and quarter has also a considerable influence.

The general practice is to place the centre of effort of the sails at some distance before the middle of the length, and in determining this distance, the shape of the fore-body is taken into consideration by diminishing the distance when the bow is very full, as in colliers and most other English merchantmen, and the rule is found to answer for this sort of vessel,

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[1] See 'Complete Theory of the Construction and Properties of Vessels, by Leonard Euler, translated by Henry Watson.' London, 1776. page 123.

which is very full aft; but it is not applicable when the after-body is sharp, and the difference of draught of water is less considerable. In Swedish ships it is usual to place the centre of effort of sails rather before the centre of gravity of the vessel, and the shapes of the fore and after body are taken into consideration in determining what fraction of the length the distance between the two centres should be. In men of war, which are generally sharp, though the position of the centre of gravity, with respect to the middle of the length, may differ considerably, this method is found to answer better than the former; but when the shape is very different from that commonly used, it is equally inapplicable. In fact, it may be concluded from what has been already said, that no method that is not founded upon a comparative measurement of the different causes upon which the lateral resistance depends, can be relied on with any degree of certainty, and as the law for the resistance of fluids is undecided, it is only from experiment that an approximation to such a measurement can be made.

The immersed part of the longitudinal plane passing through the middle of the vessel has undoubtedly the greatest influence upon the lateral resistance, which may be concluded from the analogy of the direct resistance being found to depend chiefly upon the greatest transverse section; this is besides visible by the effect of the gripe, or of a deep and sharp after-body. The centre of gravity of this plan is, therefore, a more correct measure for the position of the centre of effort than either the middle of the length or the centre of gravity of the vessel. The effects produced by the difference of form of the fore and after-bodies may be measured by their relative fullness by the application of the parabolic method of comparing vessels. Thus the centre of gravity of the longitudinal and vertical plane, and the exponents of the fore and after-bodies, ought to be calculated in vessels, the centre of effort of the sails of which are known. By an interpolation from the results thus obtained, a rule may be deduced for fixing the proper positions of the masts sufficiently accurate for practice. In applying the parabolic method, the fore and after-bodies should be reckoned from the sections at which the vessel begins to diminish, as the sides of the vessel in midships are parallel to the middle line,

and the influence they have upon the question is measured by the longitudinal plan.

The method of obtaining an approximate solution of this problem, being wholly dependent on experiment, nothing can be said respecting the functions under which the exponents of the fore and after-bodies ought to appear in the formula for the centre of effort.

The waves have a considerable influence upon this centre. Thus it often happens that vessels which carry their helm to windward in smooth water, will carry it to leeward when there is a heavy swell on the windward bows. This difference is most visible when the bow is full, but the effect cannot be measured, as the waves differ so considerably in magnitude. It should be remarked, that the centre of effort of the sails which are used in strong winds ought to be further forward than that of the sails used in light winds, both on account of the greater inclination of the vessel and of the greater curvature of the sails, which has a tendency to bring the centre of effort of each sail further aft. In ships of the line this is more necessary, as the centre of effort of the wind on the hull is further abaft the middle, on account of the poop, and will consequently have a greater effect in drawing the common centre of effort aft when the area of sails is diminished.

Art. XXXIV.—*Analysis of M. Marestier's Report on the Steam Navigation of the United States of America.*

The introduction of cannon in naval warfare, and the discovery of the Mariner's Compass, were necessarily the causes of most important changes in the forms of ships. Battles had hitherto been decided by a series of hand to hand encounters between the crews of opposing fleets, and the impetus of shocks given with the armed prows of the vessels. The most extensive voyages were scarcely more than from one known headland to another, and the dangers of navigation were only guarded against by the facilities for gaining shelter.

For both the purposes of war and navigation then, it was

requisite to have vessels which would accommodate a great force of rowers. But with cannon, and the ability of performing long voyages, came also the necessity for large and high vessels, in which it was found impossible to use oars advantageously; but the great uncertainty attendant on the wind, as the sole source of motion, made it a desideratum to supply its action, when it was either inadequate, or when its direction was contrary to that required. There were two methods of effecting this, either by using the force of the crew of the vessel in some efficient manner, or by substituting some other force; and we find that a series of attempts have at different times been made to accomplish both methods; the use of paddle wheels may be traced to a very distant period; condensed air, gunpowder, and the fall of water, have been proposed as motive powers.

In France and in England different individuals have attempted to supply both the force, and the manner of its application. In the year 1753 the Academy of Sciences at Paris offered a prize for the best memoire on the subject, "Sur la maniere de suppléer à l' action du vent sur les grands Vaisseaux." This gave rise to three Papers, from Bernoulli, Euler, and Mathon de la Cour. The prize was adjudged to Bernoulli. His Memoire contains several useful investigations and observations. With a view to determine the velocity which may be expected by using the force of the crew of a ship as the propelling power, he has endeavoured to ascertain the mean strength of a man, which he fixes to lifting twenty pound through three feet in a second for eight hours a day, or sixty pound through one foot; he then investigates what portion of this force is actually usefully exerted, to overcome the resistance of the water, by a man in the action of rowing, which he determines to be ,446 of the whole force. He then takes the plane of resistance of a first-rate, as given by Bouguer, at 150 square feet, and on these data and the following, he calculates a table, showing the velocities which might be communicated to a vessel by means of her crew, if it were possible to employ the whole force of each man usefully; and also the velocities which would be communicated by means of oars, could they be applied, or by any other method with only equal dis-

advantages. The whole of this table is founded on the supposition that the power required to produce any given velocity, is as the cube of that velocity, while the resistance is as the square of the velocity. As this is contrary to the opinion of many practical Engineers, who believe the power required to be only as the square of the velocity, it may not be amiss to give Bernoulli's proof of his hypothesis.

He supposes the direct resistance of the water against the resisting surface of the vessel to be equal to the weight of a column of water, the base of which, r, is equal to the resisting surface, and its height, a, is that due to the velocity of the vessel. This weight he supposes, by means of a rope passing over a pulley, to be lifted with a velocity equal to that of the vessel, that is, with the velocity which a body would acquire in falling from the height due to the velocity of the vessel. Now this velocity $= 2\sqrt{15\,a}$, and the moment of the force required will be $= 2\,r\,a\sqrt{15\,r\,a}$. Then supposing $2\sqrt{15\,a} = c$

$$a = \frac{c^2}{60}$$

Therefore $2\,r\,a\sqrt{15\,a} = \frac{r\,c^3}{60}$

That is,—the exertion necessary to communicate any given velocity to the vessel, must be as the cube of that velocity.

Now, if $\frac{r\,c^3}{60}$, the whole force required, be divided by 60, the force of one man, the result will be, n, the number of men,

$$n = \frac{r\,c^3}{3600}$$

and $c = \sqrt[3]{\frac{3600\,n}{r}}$, the number of feet in a second which would be communicated to a vessel by the number of men, n, if none of the force they exerted were lost by the manner of its application. It has been proved by experiment that the same number of men, by very great extra exertion, may increase this velocity in the proportion of 1 to the $\sqrt[3]{\frac{175}{92}}$. The velocities contained in the third and fifth columns of the table are the results of this proportion.

Table of the Velocities which may be attained in a first-rate by the force of men.

Number of Men to be employed	Theoretical velocities, no force being lost.		Practicable velocities, a part of the force being lost.	
	Possible velocity in a second, with ordinary and durable exertion.	Possible velocity in a second, with extreme exertion.	Velocity in a second with oars, with ordinary and durable exertion.	Velocity in a second with oars, with extreme exertion.
	Feet.[1]	Feet.	Feet.	Feet.
10	1,50	1,86	0,60	0,75
20	1,90	2,35	0,85	1,05
30	2,17	2,69	1,03	1,27
40	2,39	2,96	1,18	1,46
50	2,58	3,19	1,31	1,62
60	2,74	3,39	1,43	1,77
70	2,88	3,57	1,54	1,91
80	3,01	3,72	1,64	2,03
90	3,13	3,87	1,73	2,14
100	3,25	4,03	1,81	2,24
120	3,45	4,27	1,96	2,43
140	3,63	4,49	2,10	2,60
160	3,80	4,70	2,23	2,76
180	3,95	4,89	2,36	2,92
200	4,09	5,06	2,48	3,07
220	4,22	5,22	2,59	3,21
240	4,34	5,37	2,69	3,34
260	4,46	5,51	2,79	3,46
280	4,57	5,65	2,89	3,58
300	4,68	5,79	2,98	3,69
350	4,93	6,10	3,19	3,95
400	5,16	6,38	3,39	4,20
450	5,36	6,63	3,57	4,43
500	5,55	6,86	3,73	4,63
550	5,73	7,09	3,88	4,82
600	5,90	7,31	4,03	5,00
650	6,06	7,50	4,17	5,17
700	6,21	7,69	4,30	5,34
800	6,50	8,04	4,55	5,65
900	6,76	8,37	4,79	5,91
1000	7,00	8,68	5,01	6,21

At first it appears impossible that the table can be correct, or that the force of ten men, if the whole were usefully employed, could communicate to a first-rate a velocity of one foot and a half in a second. But, he observes, that if the theory of the resistance of fluids be correct, the resistance experienced by

[1] The English foot is equal to ,9383 French feet.

the vessel, with that velocity, will be about four hundred pounds, that is, forty pounds to be overcome by each man, which is by the estimate precisely the exertion he is capable of. Taking the force of the ten men to be employed as advantageously as it would be with oars, if they could be used, his result is, that the first-rate[1] would be moved ,6 of a foot in a second, a velocity very great to be communicated by so small a number of men; and Bernoulli observes, that if this result does not agree with practice, it proves that the theory of resistances is incorrect when applied to large bodies moving with small velocities.

The table is, however, useful, as it may serve as a guide to determine what may be expected from any method which has for its object to endeavour to propel a ship by the force of its crew.

Bernoulli suggests the following method for determining the resistance experienced by any vessel, and for making experiments to ascertain whether the rule, that the resistance is as the square of the velocity may not need some correction when applied to large surfaces. The ship on which the experiment is to be made should be connected by means of a rope to another, which is intended to tow it. The rope, which should be of sufficient length to prevent the aftermost vessel being affected by the motion caused in the water by the foremost, should have one end firmly secured to the towing vessel, and the other end, which is on board the vessel of which the resistance is to be determined, should pass over a pulley, and then hanging vertical should be charged with weights, which at first may be heavy enough to sustain the pull of the towing vessel without lifting, but when the velocity of the vessel has become uniform, the weight should be diminished till the strain has an effect on it. Then if the velocity of the vessel be correctly observed, the weight which remains will show the force which it required to produce it. This method might be much more easily applied to steam boats than to sailing vessels; but at the same time the resistance of the air and the state of the wind must be considered, which Bernoulli has neglected.

It is a curious fact, that in the course of this Memoire, Bernoulli mentions his having read the description of a steam en-

1 A first-rate is now at least one-third larger than in Bouguer's time.

gine, and makes the remark, that he does not consider its force, however it may be improved, can ever be advantageously applied to the purposes of navigation.

The book, which is the subject of this paper, is the result of a voyage made to America by its author, M. Marestier, an Engineer in the French Royal Marine, and a Chevalier of the Legion of Honour, by the direction of the French Government, to collect every information on the subject of Steam Navigation, which he might consider could be of advantage to the French Marine. The book was printed at the Royal press, and published by the command of the Minister of the Marine and Colonies. It was published in 1824. The author commences with a short sketch of the historical progress of Steam Navigation, or rather of the means which have been used as substitutes for the force of the wind; he then gives an account of the American steam boats, with their dimensions and velocities, and a very minute and technical description of the engines on board of them. Afterwards, from the data he has collected, he investigates the principles by which to determine the proportions existing between the size of the vessels and the power of the engines, in order to obtain a determinate velocity. An Appendix contains descriptions of the American schooners, and of several machines applicable to nautical services, which he saw during the course of his researches. The book is accompanied by a large folio of plates, principally of the engines and machines above mentioned.

It appears from the historical part of his Memoire, that England claims the honour of the first proposal for a boat to be propelled by the use of a steam engine. In the year 1736 Mr. Jonathan Hulls took out a patent for a boat to be propelled by the aid of steam. On the plea that Jonathan Hulls' plan was never executed, M. Marestier claims the honour of the first introduction of steam boats for a native of France, M. Perier, who made some experiments on the Seine with a boat propelled by a steam engine in 1775; but, as he confesses that this gentleman's attempt was a failure, it cannot of course have any claim to priority of introduction, much less of invention, to that of Jonathan Hulls.

Several attempts were made by different persons without any

great success until the year 1801, when a steam boat was tried on the Clyde by Mr. Symington, which is said to have succeeded, and was only laid aside on account of the injury it was found to do to the banks of the river; however, the first steam boats which appear to have at all answered the expectations of their projectors were built in America. In the year 1807 Mr. Fulton launched a steam boat at New York, and his success was such, that he has since borne a great share of the credit due to the inventor. In the article on Steam Navigation in the Encyclopædia Britannica, there is a letter of Mr. Symington's, in which he says, that Mr. Fulton saw his boat on the Clyde, and that he asked permission, which was granted, to make such memorandums as he might deem necessary.

That Mr. Fulton was the first, who succeeded in his attempts, M. Marestier fairly attributes to his having also been the first who endeavoured to investigate on principle the difficulties of the subject. His calculations were founded on the results obtained by the Society for the Improvement of Naval Architecture, which existed in England from 1793 to 1798. M. Marestier has described at some length his method of proceeding. It is in principle thus: having determined the resistance which his vessel would meet with, as the paddles must experience an equal resistance, the engine must exert a force at the centre of effort of the paddles equal to the resistance of the vessel; then assuming that the velocities of the piston and of the paddles are known, he says that the velocity of the piston is to the velocity of the paddles, as the force on the paddles is to the force on the piston; and by dividing the whole force on the piston, by the force the steam will exert on any portion of its surface $= a$, the surface of the piston is obtained, the square root of which will be the diameter.

Then, knowing the whole resistance on the paddles, and supposing only one paddle on each side to act at the same instant, the area corresponding to the resistance is known, half of which area will give the surface of one paddle; and knowing from the number of strokes made by the piston the number of revolutions the paddle-wheels will make, the diameter of the wheel can be determined, so as to ensure to the paddle the velocity at first assumed.

Fulton having in this manner determined the force necessary to propel his boat, and the measures which were to be taken to facilitate the application of that force, necessarily succeeded, having avoided the error which had caused most of the failures up to his time—that of attempting too much with an inadequate power. From the success of this essay Steam Navigation made rapid strides in the United States, and is now in general use on all the lakes and rivers of that vast territory. In the year 1812, a steam boat was launched on the Clyde, which river was the nursery of the system in this country, and we have followed the example of America in its general adoption. In little more than half a century after a man of Bernoulli's eminence had prophesied the improbability of its success, and in less than twenty years from its first successful essay, Steam Navigation has arrived at such perfection that the longest and most hazardous voyages have been attempted,[1] and the attempts have succeeded in such a degree, as to warrant the hope, that the experience of a few more years will enable them to be reckoned on as things of certain occurrence.

The second division of the book is on the form and dimensions of the American boats. M. Marestier has not given any detailed account of the shapes of the bodies, but his tables of relative dimensions are copious. It appears that until 1813 they were all constructed with flat bottoms, and that the Fulton was the first which had any rising in the floors.

That it is to a certain degree advisable to assimilate the form of steam boats, to that which is usual for sailing vessels, is probably correct; at the same time there are several circumstances which must be considered, especially the nature of the navigation for which they are intended,—if for the open sea, an increase to their draught of water can be given should any advantage be gained by it, but in rivers and lakes, as the water is more shallow, it is often necessary, and always advantageous, to have very little draught of water, for from the experiments

[1] The Atlantic has been repeatedly crossed by means of steam, and a steam boat has reached India from England. M. Marestier says the first boat which crossed the Atlantic was the Savannah, she performed the passage from Savannah to Liverpool in 26 days, and consumed 210 tons of coals.

which have been made on the resistances of fluids, it has been proved that the quantity of water beneath the body in motion has a very important effect on the resistance it experiences, and if at all confined, the resistance is very much increased; this is also a common remark among watermen, and it has been observed in steam boats of different sizes on the same river, where as long as the water continued shallow the smaller boat has had the advantage, but gradually as the water deepened, the larger boat has increased her comparative velocity. The same observation applies to the necessity of having the area of the midship section as small as possible in boats destined for canals and narrow rivers, as the resistance depends on the proportion the area of the section of the boat bears to the area of the section of the fluid.

It has been found that steam boats have a very considerable rolling motion, owing to the small proportion their breadth bears to their length, and to the height of the centre of gravity of the principal weights, as the engine, &c. Of course as this motion arises from a deficiency in stability, it would be advantageous to adopt the form most conducive to that quality. It is also of importance to have the greatest displacement with the least direct resistance, that is, with the least area of midship section, this, supposing the area of the midship section and the breadth to be given, is in favour of a form full near the load-water-line and lean below; in such a body also the centre of gravity of the displacement is high, which is advantageous in point of stability; and it enables the body forward and aft to be made finer than could be the case with a flat floored midship section. The rising of the floor must, however, be limited by the consideration, that if the engines, &c., are raised by it, the advantages might be counterbalanced by the effect this would have in raising the centre of gravity of the vessel.

There is one great advantage in the extra draught of water, which results from the adoption of the rising floor,—that the keel, which, by its direct opposition to the water must act very much to diminish the rolling motion, is at a greater distance from the axis of rotation, and consequently has a proportionately greater effect. The rising floor is now generally adopted in the English steam boats.

The shape of the sides between wind and water should be paid particular attention to, for the form of the body in this part has a most material influence on the easiness of the rolling motions of the vessel: care should be taken that the moment of stability shall increase rapidly but easily, and that during the alternate oscillations of the vessel, the centre of gravity of the displacement shall remain in the same transverse section;[1] also the form of the body above and below the water-line should be so adapted to the situation of the centre of gravity, that the oscillations may take place without any alteration in the axis of rotation, which would necessarily cause a rising or falling motion in the ship; and it is very necessary that the chimney should be kept as low as possible, as its weight, by raising the centre of gravity of the vessel, diminishes the stability, and the great momentum it acquires in its vibrations must not only increase the rolling motion, but be very liable to carry it away, especially if the stability is not well graduated. In fact, for the accommodation of the passengers and for the security of the engine, every precaution should be taken to render the motions and strains, to which a steam boat is subject, as easy as possible.

In the English boats the engines are placed so that the axis of the paddle-wheel is generally below the deck. In the American boats it is generally above, and even some of their boats destined for merchandize have, according to M. Marestier, the engines on their deck: however, as the sides of steam vessels are generally nearly vertical for some distance both above and below the water section, it would be advantageous with regard to easiness of motion, to endeavour to adjust the different weights so that the centre of gravity of the boat should be nearly in that plane.

At first it was usual to construct the boats with very great comparative length, in imitation of the relative proportion of row gallies; not considering that the chief reason for the great length of those vessels was to gain space for the rowers, whose weight was therefore equally dispersed throughout the length. But in steam boats, in which the principal weights are neces-

[1] See Dr. Inman's Notes on Chapman.

sarily concentrated, the inequality of the strain this causes must be a great source of weakness. In steam boats for rivers and canals the proportion of the length to the breadth may be larger than for those intended for the sea, as they are less exposed to great strains, at the same time great length requires great space for turning, which may often prove very inconvenient.

The following table of lengths and breadths, given by M. Marestier, shows that experience proved the necessity of diminishing the relative proportions of the length.

Lengths and Breadths of the American Steam Vessels.

NAMES OF THE VESSELS.		Length.	Breadth.	Relation of the length to the breadth.
		Metres.[1]	Metres.	
Built at Boston	The Massachusetts	25,00	5,50	0,220
	— Clermont in 1807	42,67	4,57	0,107
	— Clermont in 1808	45,72	4,87	0,107
Built at New York	— Car of Neptune	53,34	7,16	0,134
	— Paragon	52,73	8,23	0,156
	— Fire Fly	30,48	5,64	0,185
	— Richmond	46,63	8,53	0,183
	— Washington	40,00	6 40	0,160
	— Fulton	40,54	8,84	0,218
	— Olive Branch	37,80	8,84	0,234
	— Connecticut	42,67	10,06	0,236
	— Chancellor Livingston	47,55	10,06	0,212
	— Bellona	28,00	6,25	0,223
	— Robert Fulton	48,16	10,06	0,209
	— Savannah	30,48	7,92	0,260
Built at Philadelphia	— Delaware	41,34	6,10	0,148
	— Philadelphia	42,75	6,10	0,143
	— Ætna	34,75	5,50	0,158
	Boat of the Union Line	41,50	5,75	0,139
Built at Baltimore	Boat being broken up	42,00	6,32	0,150
	The Eagle	34,00	5,88	0,173
	— New Jersey	38,00	5,88	0,155
	— United States	42,64	7,62	0,179
	— Virginia	41,45	7,56	0,182
	— Norfolk	41,00	7,70	0,188
	— Surprise	28,65	4,75	0,166
	— Maryland	41,76	7,92	0,190
Built on the Mississipi	— Vesuvius	48,77	8,53	0,175
	— Enterprize	24,38	8,84	0,363

[1] The Metre is equal to 3,2819 English feet.—The last column in this table is obtained by dividing the breadth by the length.

Draughts of Water of the American Steam Vessels.

NAMES OF THE VESSELS.		Draught of Water.
		Metres.
At Boston	The Massachusetts	1,30
In the Strait of Long Island	— Fulton..................	1,90
	— Connecticut	2,08
On the Hudson......	— Paragon	1,25
	— Richmond	1,60
	— Chancellor Livingston....	1,83
At New York........	— Olive Branch	1,37
	— Nautilus	1,37
At Philadelphia......	— Philadelphia	1,22
	— Pensylvania	1,22
	— Ætna	1,22
	— Bristol	1,22
	Boat on the Union Line.......	1,37
	— Delaware	1,37
At Baltimore........	Boat being broken up........	1,30
	The Norfolk	1,52
	— Virginia..................	1,52
	— Maryland	1,52
	— Surprize.................	1,22
	— United States	1,52
On the Potomac......	— Washington	1,73
At Norfolk..........	— Powhatan	1,37
On the Mississipi	— Vesuvius	1,80
	— Robert Fulton	3,05
On the Ocean	— Savannah	4,27

The draughts of water are given in a separate table, because it is a dimension which, as has been before said, depends so much upon local circumstances; however, all things considered, there is no necessity even for steam vessels intended for the sea to have so great a proportion of depth as is given to sailing vessels, for their great length and straight of breadth will, in the event of their using their sails, supply the place of depth, any useless degree of which serves only to increase the resistance: neither can there be any advantage in a difference of draught of water forward and aft in boats constructed with a rising floor, but probably with flat floors it may be requisite, to assist the action of the water on the rudder.

M. Marestier has given the drawing of only one American boat, the Chancellor Livingston, so that we cannot form a correct idea of the general character of their bodies; we have, for the sake of comparison, given the exponents of her different

elements, after Chapman's method, together with those of several English boats, and two which have been lately constructed in England for the service of the Norwegian[1] government.

	Length of the construction Water Line.	Depth to the tangent of the Midship Section.	Exponent of the Line of Sections.	Exponent of the Midship Section.	Exponent of the Water Line.	Exponent of the Displacement.
	Feet.	Feet.				
English Boats	117,7	7,8	2,7	3,45	5,002	2,10
	98,8	6,2	2,47	5,75	5,206	2,60
	99,8	7,1	2,32	6,96	6,39	2,41
Norwegian....	106,8	6,85	2,5	3,55	6,10	2,00
	95,75	6,25	2,4	4.54	6,54	2,13
American	150,47	5,41	2,12	4,72	4,03	2,27

The constant weights on board a steam boat being considerable, and also very much concentrated, it is of importance that not only the displacement but the situation of its centre of gravity should be very accurately determined. It is usual to distribute the coals as nearly about this centre as possible; the station of the centre of gravity of the engine, &c., should be adjusted with reference to the probable purposes to which the vessel is to be appropriated, as that will in a great degree determine the situations of the rest of the weights which she will have on board. It would be proper always to give an estimate of the stability of the vessel with regard to her length, by calculating what weight if removed a certain distance either forward or aft from the centre of gravity will make a certain difference in the draught of water; this being known it would serve as a scale by which any alteration in the disposition of the weights might be regulated; by a neglect of these precautions it very often happens that steam boats do not swim to the draught of water intended, and sometimes appear very much by the head. The great rake which is generally given to the

[1] By Mr. A. G. Carlsund, after the parabolic method, of which he gave an account in the last Number of this work.

stem, by raising the direction of the resultant of the resistance too high, will in some cases render this being by the head advantageous.

Unless the displacement is correctly determined, and the area of the midship section consequently a known, and a constant quantity, the power of the engine cannot be fixed so as to ensure a given velocity. Another cause for accuracy with regard to the displacement is, that any alteration from the water-line, in relation to which the height of the axis of the paddle-wheels was determined, might materially affect the action of the paddles; the height of the axis being adjusted in such a manner, that the wheels having a certain diameter, the paddles may have a dip in the water, which shall be such, that their inner edge shall have at least a velocity equal to that of the vessel, to ensure there being no resistance on the fore-side of the paddle. From this, it appears, that the depth of the paddle depends on the proportion the velocity of the vessel bears to that of the outer edge of the paddle-wheel. It is also found in practice, that the paddles will not work well if immersed in the water more than eighteen inches or two feet. This is on account of the great loss of power, occasioned by the obliquity of the stroke on their entrance into, and on their leaving the water, and the great quantity of water they will lift.

The breadth of the paddle must depend principally on local circumstances, always considering, that the larger the area of the paddle is, the less is the loss of power occasioned by the motion it communicates to the fluid it strikes. Bernoulli estimates this loss for the common oar to be ,297 of the whole force applied.

It is found in practice, that sea-going boats should generally have their paddles narrower than boats intended for smooth water.

The number of paddles on the wheel is wholly determined by practice, one paddle for every foot the wheel is in diameter is the general rule followed; if they are too near each other, they do not meet the water with the greatest advantage, and if they are too far apart, the motion, which their successive and distinct impact with the water communicates to the vessel, is unpleasant.

M. Marestier says, it is not yet well determined where the axis of the paddle-wheel should be placed, with regard to the length of the vessel;—he gives the following table of its situation in several American boats: however, its position is always very much limited by that of the engine:—

Situation of the Paddle Axis.

NAMES OF THE VESSELS.	Distance from Forward.	Distance from Aft.
	Metres.	Metres.
The Chancellor Livingston	23,775	23,775
— Fulton	10,12	10,42
— Bellona	12,00	16,00
— Delaware	16,64	24,70
— Philadelphia of Trenton	18,25	24,50
— United States	15,64	27,00
— Virginia	15,26	26,19
— Norfolk	16,00	25,00
— New Jersey	17,00	21,00
— Philadelphia of Baltimore	14,00	27,00
— Eagle	14,00	20,00
— Washington	14,50	25,50
— Powhatan	16,50	18,50

Many of the boats on the Mississipi have the wheels abaft, that they may be more sheltered from the logs of timber which are constantly floating on that river; and many vessels which are only intended for short passages, and where small draught of water is necessary, are built with two bodies and the wheel between them: but this plan is not found advantageous for boats with any considerable draught of water, as, besides their being very weak, there is an increase of resistance resulting from the water passing with great velocity through a confined channel. Boats have been tried with two pair of paddle-wheels, and the Dutch are now building a steam frigate with four engines, each of 100 horse power, to act on two pair of paddle-wheels.

When there are two paddle-wheels on each side, their relative velocities, with respect to the fluid they act on, should be equal, that they may exert an equal force to propel the vessel; if this were not the case, the aftermost wheel would be disadvantageous: but as the water on which the aftermost wheel

acts has had an increased velocity communicated to it by the foremost wheel, the absolute velocity of the aftermost wheel must be proportionately greater than that of the foremost, which will require a greater quantity of steam, and consequently a greater consumption of fuel; there would also be a waste of power, unless each pair of wheels had separate engines: and it is probable that the aftermost wheels would lose a portion of their effect in consequence of the disturbed state of the water they would act in.

This table is followed by a valuable one, which was given to M. Marestier by one of the first engineers of New York, as the result of his experience and opinions with regard to the proper proportions necessary between the dimensions of the vessel and the engine; and, in order to make this part of his work as complete as possible, M. Marestier has added a nearly similar table of his own collecting, containing the principal proportions of the engines and paddle-wheels, &c., of the boats, of which the dimensions have been given in the preceding tables.

A Table of the principal Proportions of Steam Engines as adapted to Vessels of known dimensions.

Dimensions of the Vessel.	Burthen	Tons. 160	Tons. 200	Tons. 260	Tons. 320	Tons. 400	Tons. 500
	Length on the deck	Metres. 22,5	Metres. 27,0	Metres. 33,0	Metres. 37,5	Metres. 40,5	Metres. 42,0
	Breadth	6,6	7,2	8,1	9,6	10,2	10,8
	Draught of water	1,2	1,5	1,8	2,1	2,4	2,55
Horse-power of the Engine		No. 20	No. 30	No. 40	No. 60	No. 80	No. 100
Diameter of the Cylinder		Metres. 0,60	Metres. 0,75	Metres. 0,93	Metres. 1,00	Metres. 1,10	Metres. 1,20
Height of the Cylinder		1,50	1,50	1,55	1,55	1,80	1,80
Length of the Boiler		4,80	6,00	6,00	6,60	6,60	7,20
Breadth of ditto		2,40	2,55	2,70	3,00	3,15	3,60
Height of ditto		2,10	2,40	2,40	2,70	3,00	3,00
Diameter of the Paddle-wheels		4,80	5,10	5,40	5,40	5,70	6,00
Length of the Paddles		1,50	1,65	1,80	1,80	2,10	2,10
Depth of ditto		0,60	0,60	0,75	0,90	0,90	0,90
Weight of the Engine		Tons. 20	Tons. 25	Tons. 30	Tons. 35	Tons. 40	Tons. 45

Dimensions of the Engines and Paddle-wheels of the Vessels contained in the former Tables.

NAMES OF THE VESSELS.	Date of the Construction.	Diameter of the Piston.	Stroke of the Piston.	Diameter of the Wheels.	Number of the Paddles.	Length of the Paddles.	Depth of the Paddles.
		Metres.	Metres.	Metres.	No.	Metres.	Metres.
The Clermont	1807	0,610	1,22	4,60	8	1,20	0,60
— Car of Neptune	1808	0,838	1,32	4,25	—	1,20	0,70
— Paragon	1811	0,813	1,22	4,90	8	1,30	0,75
— Fire Fly	1812	0,508	1,14	3,80	—	1,05	0,60
— Richmond	1813	0,838	1,32	4,60	8	1,20	0,60
— Washington	1813	0,711	1,22	4,50	8	1,35	0,45
— Fulton	1813	0,914	1,22	4,70	8	1,50	0,70
— Olive Branch	1816	0,914	1,22	5,00	10	1,45	0,75
— Connecticut	1816	1,016	1,37	5,20	10	1,45	0,75
— Chancellor Livingston	1816	1,016	1,52	5,50	8	1,75	0,90
— Philadelphia of Trenton	—	—	—	5,20	12	—	0,55
— Delaware	—	0,812	1,37	5,50	12	1,75	0,75
An old boat at Baltimore	—	0,740	1,22	5,30	12	0,95	0,55
The New Jersey	—	—	—	5,20	10	1,80	0,65
— Philadelphia of Baltimore	—	0,830	—	5,60	16	—	—
— Virginia	—	0,889	1,22	5,40	—	1,75	0,75
— Norfolk	—	—	—	6,00	12	1,75	—
— Maryland	1818	1,016	1,42	6,00	12	1,75	0,65
— United States	1818	1,016	1,42	5,50	10	2,00	0,75
— Massachusetts	—	—	—	5,00	8	1,80	0,80
— Robert Fulton	1819	1,130	1,52	5,50	10	2,00	—
— Savannah	1818	1,035	1,52	4,90	10	1,42	0,83

M. Marestier then gives the following comparative table of the results he has observed and calculated for ten boats, of which he was able correctly to ascertain the velocities.

In the first column, for the value of the *Elasticity of the Steam*, he gives the height of the column of mercury it will support in a vacuum.

The *Proportion of the Paddles*, is the quotient of the rectangle formed by the breadth and draught of water of the boat, divided by the area of one paddle.

The *Factor of the Diameter of the Wheels*, he explains as being obtained from the consideration, that if the vessels were similar, and the resistance to the paddles bore in all the same proportion to the resistance of the hull, the diameter of the paddle-wheels would be equal to the velocity of the boat multiplied by a constant factor, and divided by the number of double oscillations of the piston. The mean of these factors is between 29 and 30, therefore if the proportion the velocity of a steam boat bears to the number of strokes of the piston, be multiplied by 29 or 30, he says the result will give nearly the dimensions of the paddle-wheels similarly proportioned to those in the American boats.

The last column, *the Multiplier*, is a number, which he has deduced, to show the relation borne by the true velocity of the boat to the following quantity: the square root of the product of these three quantities, the height of the column of mercury the steam will support, the stroke of the piston, and the square of its diameter, divided by the square root of the product of the rectangle of the breadth and draught of water of the vessel, and the diameter of the paddle-wheel.

If the different boats were equally perfect in their several elements, there would be no necessity for a different multiplier for each boat; but as the forms of their bodies and the qualities of their engines differ very considerably, it becomes necessary that the multipliers should vary.

M. Marestier finds that the variation for the first nine boats in the table is between twenty and twenty-five; he does not include the Savannah, as he is not so certain of the correctness of his information respecting her.

Table of the comparative Proportions and Dimensions deduced from ten American Steam Boats.

NAMES OF THE VESSELS.	Elasticity of the Steam.	Number of revolutions of the Wheels in a minute.	Velocity of the Piston in a second.	Proportion of the Paddles.	Velocity of the inner edge of the Paddles in a second.	Velocity of the Vessel in a Secon.	Velocity of the Vessel in an Hour.	Factor of the diameter of the Wheels.	Multiplier.
	Metr.		Metr.		Metr.	Metr.	Miles[1]		
The Washington	0,95	20	0,81	18,1	3,77	2,57	5,0	35,0	23,70
— Fulton	1,10	18½	0,75	16,0	3,20	2,8	5,4	31,0	23,50
— Olive Branch	0,95	18½	0,75	11,1	3,39	3,0	5,8	30,8	23,72
— Connecticut	0,35	17	0,78	19,2	3,29	3,15	6,1	28,1	23,78
— Chancellor Livingston	0,95	17	0,86	11,7	3,29	2,9	5,6	32,2	23,90
— Delaware	1,30	17¼	0,80	6,4	3,67	3,5	6,8	27,5	21,90
— Virginia	1,10	18¼	0,74	8,8	3,73	3,3	6,4	29,9	25,24
— United States	1,15	16½	0,78	7,7	3,43	3,3	6,4	27,5	20,29
— Maryland	1,05	17	0,80	10,6	4,18	3.6	7,0	28,3	24,66
— Savannah	0,90	16	0,81	31,0	2,71	2,6	5,0	30,2	27,65

To understand more clearly the method in which M. Marestier deduces the two quantities he has called *Factor* and *Multiplier* in this last table, it will be necessary to follow him through some part of his theoretic investigation of the principles of the motion of steam boats.

He commences with the supposition, that the motion of the vessel is become uniform, and that the force of the steam is constant, and on this hypothesis, and the data he has collected in the last table, he investigates the proportions which exist between the power of the engine, the dimensions of the vessel, and the sizes of the wheel and paddles.

He assumes,—That the resistance of the paddles is equal to the resistance of a surface moved in the fluid in a direction perpendicular to itself, and with a velocity equal to the mean velocity of the paddles.

This surface, which he calls the *resisting surface of the pad-*

[1] The nautical mile is equal to 1851,85 metres, that is, to about 6077,58 English feet.

dles, he supposes equal to a^2, and its velocity in a second to be U. These two quantities are to be determined by experiment, as also are two others: the *resisting surface of the vessel,* which he supposes equal to b^2, and the velocity V of the vessel.

1. The resistance of the hull being proportionate to the square of the velocity, is equal to $k\,b^2\,V^2$, k being the direct resistance corresponding to the unity of surface and velocity.

Then the velocity with which the paddles strike the fluid being $U - V$, the resistance they experience is $= k\,a^2\,(U-V)^2$, and

$$k\,b^2\,V^2 = k\,a^2\,(U-V)^2,$$

$$\text{and } U = \left(1 + \frac{b}{a}\right) V.$$

Therefore the velocity of the vessel is always in proportion to that of the paddles, while the resisting surface of the vessel bears a constant relation to that of the paddles.

2. The moments of the two forces, the action of the paddles on the water, and of the steam on the piston, will be equal, with the exception of the effect of friction. Now the absolute velocity of the paddles is U, and the resistance they experience is $k\,a^2\,(U-V)^2$; therefore the moment of their action will be $k\,a^2\,(U-V)^2\,U$.

And suppose q to represent the density of the mercury, h the height of the column which the steam will support, P the surface of the piston, and v its mean velocity; the moment of the piston will be equal to $q\,h\,P\,v$. Therefore,

$$q\,h\,P\,v = k\,a^2\,(U-V)^2\,U.$$

3. The effect of the friction of the machine is then introduced in the expression, and as it diminishes the moving force, which should be communicated from the piston to the paddles, a portion of the moving force $q\,h\,P$ is taken, as $m\,q\,h\,P$; then

$$m\,q\,h\,P\,v = k\,a^2\,(U-V)^2\,U,$$

$$\text{and also } U = \left(1 + \frac{b}{a}\right) V.$$

$$\text{Consequently } V = \sqrt[3]{\frac{m\,q\,h\,P\,v}{k\,b^2\left(1+\frac{b}{a}\right)}}$$

$$\text{and } U = \sqrt[3]{\frac{m\,q\,h\,P\,v}{k\,b^2}\left(1+\frac{b}{a}\right)^2}$$

4. From which the following conclusion may be drawn:— that the cube of the velocity of the vessel is less than the power of the engine, divided by the resistance of the vessel; and that the cube of the mean velocity of the paddles is greater than the same quantity; which is a limit of the cubes of either velocity, only to be attained when the paddles are infinite.

5. Suppose a second boat, in which U′, V′, *a*′, *b*′, &c., will correspond with U, V, *a*, *b*, &c., in the first boat, and finding the values of V′ and U′,

$$\frac{V'}{V} = \sqrt[3]{\frac{m' h' P' v'}{m h P v} \cdot \frac{b^2}{b'^2} \cdot \frac{1 + \frac{b}{a}}{1 + \frac{b'}{a'}}},$$

$$\text{and } \frac{U'}{U} = \sqrt[3]{\frac{m' h' P' v'}{m h P v} \cdot \frac{b^2}{b'^2} \cdot \left(\frac{1 + \frac{b'}{a'}}{1 + \frac{b}{a}}\right)^2}.$$

And when the resisting surfaces of the paddles are, in the two vessels, proportional to the resisting surfaces of the hulls,

$$\frac{b'}{a'} = \frac{b}{a};$$

$$\text{and, consequently, } \frac{V'}{V} = \frac{U'}{U} = \sqrt[3]{\frac{m' h' P' v'}{m h P v} \times \frac{b^2}{b'^2}}.$$

That is, that the velocities of the boats are in proportion to those of the paddles, and also are in direct proportion to the cube root of the power of the engines, and in inverse proportion to the cube root of the resistance of the vessels. He considers this proposition nearly general, as, unless there is a very great disproportion between the two vessels, the relation of $1 + \frac{b}{a}$ to $1 + \frac{b'}{a'}$ cannot differ much from unity.

Throughout these investigations, the author has taken *h*, the height of the column of mercury which the steam which acts upon the piston will support, and determined the effort of the piston apparently under the supposition that the vacuum on the contrary side of the piston is perfect; but, as that is not the case, the quantity, *h*, should be diminished by the height, which, the steam remaining on the contrary side of the piston, will depress the mercury from the altitude at which it should stand in a common barometer. This becomes of consequence in comparing one boat with another, for, of course,

the greater or less degree of vacuum depends totally on the goodness of the engine.

6. From the two equations, $b\,V = a\,(U - V)$, and $m\,q\,h\,P\,v = k\,a^2\,(U - V)^2\,U$, it may be deduced that

$$U\,V^2 = \frac{m\,q\,h\,P\,v}{k\,b^2}.$$

Therefore, whatever may be the size of the paddles, the product of their velocity and the square of the velocity of the vessel is in proportion to the power of the engine.

Although the power of the engine has been considered as already determined, it is seldom that the velocity of the piston can be taken arbitrarily. The relation between this velocity and that of the paddles is almost always invariable, and therefore the velocity of the piston alters with any increase or diminution in the size of the paddles. This does not make any change in the correctness of the foregoing equation, but v will change according to the alteration; and it may happen either that the velocity of the piston is too great to allow an adequate supply of steam, or that there is too great a supply of steam, and therefore some necessarily passes by the safety valve. In the first case, the elasticity will diminish until the movement of the piston shall be no more than enough to consume the quantity of steam supplied; and, in the second case, to prevent the loss of steam and the consequent too great consumption of fuel, the fire must be diminished; but then the power of the engine will be reduced in the proportion of the actual velocity of the piston to that which it ought to have.

That the velocity of the piston may correspond to the quantity of steam furnished by the boilers, the mechanism must be so arranged that the velocity, U, of the paddles shall equal

$$\sqrt[3]{\frac{m\,q\,h\,P\,v}{k\,b^2}\left(1 + \frac{b}{a}\right)^2},$$

or if r be the relation between the velocity of the piston and that of the paddles, so that $r = \frac{U}{v}$, that is,

$$= \sqrt[3]{\frac{m\,q\,h\,P}{k\,b^2\,v^2}\left(1 + \frac{b}{a}\right)^2}.$$

7. By means of the three equations $U = \left(\ + \frac{b}{a}\right) V$, $m q h P v = k a^2 (U - V)^2 U$, and $U = r v$, we are able to determine three of the eight quantities, a, b, h, P, r, U, V, v, when the other five are known; for example, considering U, V, and v, as unknown, we find

$$U = \left(\frac{1}{b} + \frac{1}{a}\right) \sqrt{\frac{m q h P}{k r}}, V = \frac{1}{b} \sqrt{\frac{m q h P}{k r}},$$

$$\text{and } v = \left(\frac{1}{b} + \frac{1}{a}\right) \sqrt{\frac{m q h P}{k r^3}}.$$

Since the value of V does not at all depend upon a, it results, that as long as r, which is in proportion to the diameters of the wheels, remains the same, the surface of the paddles may be either increased or diminished without producing any change in the velocity of the boat. At the same time, from an inspection of the value of v, it appears that we cannot increase the dimensions of the paddles without diminishing the velocity of the piston, and causing a greater consumption of steam and fuel.

If the diameter of the wheels be diminished, the velocity of the boat will increase; but the velocity of the piston and the power of the machine will be increased also, which will require a greater consumption of steam and fuel. Consequently an increase of velocity may be obtained by diminishing the diameter of the wheels, provided that the boiler will furnish more steam than the engine consumes.

By increasing the diameter of the wheels the vessel will lose velocity, but this cannot be avoided; if, after having increased the surface of the paddles as much as is consistent with other circumstances, it is found that the engine has too great a velocity for the supply of steam furnished by the boiler.

If the diameter of the wheels be diminished by taking away a part of each paddle, the velocity of the vessel will be increased, because r will be diminished, but more steam will be consumed than if the change had been made in the diameter, without diminishing the paddles.

When any alteration is made in the mechanism, by which

the motion is communicated from the piston to the wheels, the quantities, r, U, V, and v, become r', U', V', and v'.

$$V' = \frac{1}{b}\sqrt{\frac{m\,q\,h\,P}{k\,r'}},\ \text{and}\ v' = \left(\frac{1}{b}+\frac{1}{a}\right)\sqrt{\frac{m\,q\,h\,P}{k\,r'^3}};$$

and, consequently,

$$V' = V\sqrt{\frac{r}{r'}} = V\sqrt[3]{\frac{v'}{v}},\quad v' = v\sqrt{\frac{r^3}{r'^3}},\quad r' = r\sqrt[3]{\frac{v^2}{v'^2}}.$$

Therefore, when the piston does not take the velocity, which the steam furnished by the boiler would admit of its taking, if the mechanism were changed, the velocity of the boat would be reduced in proportion to the cube root of the velocity of the piston; and, in order that the vessel may acquire the velocity which the engine is capable of imparting to it, r must be diminished in inverse proportion to the cube root of the square of the velocity of the piston.

The value, $V = \frac{1}{b}\sqrt{\frac{m\,q\,h\,P}{k\,r}}$, being more simple than the value before found, will be more easy to be compared with the velocities which have been observed; but it may be further simplified.

Let p be the diameter of the piston, and ϖ the relation between the diameter and the circumference, then

$$P = \frac{\varpi\,p^2}{4}.$$

In the American vessels the wheels generally make one turn for every double stroke of the piston; therefore, supposing c to be the length of the stroke of the piston, and n the number of revolutions made by the wheels in a minute:

$$v = \frac{2\,n\,c}{60} = \frac{n\,c}{30}.$$

And calling the absolute diameter of the paddle-wheels D, the mean diameter will be δ D, where δ must be determined by experiment, then we have

$$U = \frac{n \times \varpi\,\delta\,D}{60}$$

$$\text{and, consequently,}\ r = \frac{U}{v} = \frac{\varpi\,\delta\,P}{2\,c}.$$

The surface b^2 depends on the shape of the vessel, and also

perhaps on its velocity; but as it is certain that it increases in proportion as the draught of water and the breadth increase, we will suppose it proportional to the parallelogram, B, obtained by multiplying those two dimensions together, then

$$b^2 = \beta B.$$

Where β must be determined by experiment.

Then by substitution

$$V = \sqrt{\frac{m q h P}{k r b^2}} = \sqrt{\frac{m q}{2 k \beta \delta}} \sqrt{\frac{h c p^2}{B D}}.$$

The density of the mercury, $q = 13{,}6$, and the value of k, when the body exposed to the impulse of the water is thin, as in the case of the paddles, is about ,06, unity being the weight of a metre cubed. But there are several causes which render it difficult to determine m, β, and δ, as they vary under different circumstances. The best boats will be found to be those where $\frac{m}{\beta \delta}$ is the largest.

8. For the object in view, it is sufficient to know the value of the quantity $\sqrt{\frac{m q}{2 k \beta \delta}}$, which has been called the *multiplier*. Supposing it to be represented by M, we have

$$V = M \sqrt{\frac{h c p^2}{B D}}.$$

In the table which M. Marestier has formed, and which we have given, he has found these multipliers for ten vessels, and has taken a mean of them, which mean he considers is correct enough for general use, it not being liable to more than an error of a tenth in giving the correct velocity. The multipliers, he has found, vary from 20 to 25, and he has fixed his mean as 22. But as the value of the multiplier, all things else remaining the same, depends on the perfection of the engine and the vessel, it is not at all advisable to use for one vessel a number drawn from experience on others, which may be very far inferior to it. The velocities which M. Marestier has given of the American boats, are small in comparison to those of the more modern English boats; the latter boats would therefore require higher multipliers than the former.

9. It is necessary also to substitute in the equation

$$U = \left(1 + \frac{b}{a}\right) V$$

quantities which are easy to measure. We have

$$b^2 = \beta\, B \text{ and } U = \frac{n\, \varpi\, \delta\, D}{60},$$

and supposing A to represent the area of one of the paddles, a^2 may be substituted by α A, the coefficient α depending on the number of paddles which act at the same time: then

$$\frac{n\, \varpi\, \delta\, D}{60} = \left(1 + \sqrt{\frac{\beta}{\alpha}} \sqrt{\frac{B}{A}}\right) V,$$

and consequently

$$D = \frac{60\left(1 + \sqrt{\frac{\beta}{\alpha}} \sqrt{\frac{B}{A}}\right)}{\varpi\, \delta} \times \frac{V}{n}$$

The quantity $\frac{60}{\varpi\, \delta}\left(1 + \sqrt{\frac{\beta}{\alpha}} \sqrt{\frac{B}{A}}\right)$ is that which has been called *factor of the diameter of the wheels*, and of which the mean value is thirty; if we designate it by F, we have $D = F\,\frac{V}{n}$.

10. The equations

$$V = M \sqrt{\frac{h\, c\, p^2}{B\, D}}, \text{ and } D = F\,\frac{V}{n},$$

in which the coefficients M and F, taken at their mean values, obtained from experiment, twenty-two, and thirty, will enable us to resolve the questions, relative to the proportions and principal dimensions of the engines and vessels, if they are at all similar to those of the Americans.

From the two equations, we get the value

$$n = M\, F \sqrt{\frac{h\, c\, p^2}{B\, D^3}},$$

from which we see, that though from the first of the two equations it appears it is advantageous to diminish the diameter of the wheels, that cannot be done unless the boiler will produce enough steam to admit of their performing a greater number of revolutions.

By combining the two equations, and getting rid of D, we have

$$V = \sqrt[3]{\frac{M^2}{F} \times \frac{n\,h\,c\,p^2}{B}},$$

$$\text{or nearly } V = 2{,}53 \sqrt[3]{\frac{c\,h\,p^2}{B}}.$$

His expression for the velocity of a steam boat is then, the cube root of the product of the following quantities:—*the height of the column of mercury the steam will support, the square of the diameter of the piston, the length of its stroke, and the number of times it rises in a minute;* divided by the cube root of the product of *the breadth of the vessel into its draught of water;* and the quotient multiplied by a constant coefficient.

By using this expression to calculate the velocities of the first nine vessels in the comparative table, it will be found, that the error is generally less than one-tenth of the actual value.

The coefficient 2,53 depends on the form of the vessel: it might be 2,25 for a form which would apparently experience a great resistance; or it might be 2,75, or even more, for one which was the contrary.

11. If B be considered as being unknown, then

$$B = \frac{M^2}{F}\,\frac{n\,h\,c\,p^2}{V^3} \text{ or nearly } = \frac{16\,n\,h\,c\,p^2}{V^3};$$

consequently the engine being given, we know the area of a parallelogram of which the height will be the draught of water, and the base the breadth of a vessel which the engine will move with a given velocity.

12. From the same equation, $n\,c\,h\,p^2 = \frac{B\,V^3}{16}$, we find the power it is requisite that an engine should possess, to enable it to move a given vessel with a given velocity; and we see that this force increases as the cube of the velocity.

13. We have before found, that

$$v = \frac{c\,n}{30}, \text{ or } c\,n = 30\,v.$$

By substituting this value in that of V, (10,) we have

$$V = \sqrt[3]{\frac{M^2}{F} \times \frac{30\,v\,h\,p^2}{B}},$$

and when the velocity v is equal to ,8 of a metre, which is the case in most of the American boats,

$$V = 7,3, \sqrt[3]{\frac{h\,p^2}{B}}.$$

This equation may be used in the same manner as the preceding one, to determine the size of the vessel, or the power of the engine, by supposing B or $h\,p^2$ as unknown.

M. Marestier then speaks of the disadvantage attendant on the method of rating the power of a steam engine by the number of horses it would require to perform the same quantity of work, as the nominal power of the engine, under these circumstances, depends very much on the estimated power of a horse. He proposes a method, by which the number of horse-power shall be regulated by the engine. Multiply the height of the column of mercury the steam will support, by the square of the diameter of the cylinder, and by the mean velocity of the piston; then sixty-six and two-thirds times this product will be the number expressive of the horse-power. Then the velocity will equal twice the cube root of the quotient of the number of horses, divided by the product of the draught of water into the breadth of the vessel.

The power of an engine adequate to give a required velocity to a boat, may be found by multiplying the cube of the velocity by the breadth, and by the draught of water, and dividing the product by 7,26, or by 6, if the vessel is such that she will experience great resistance.

And the surface of the parallelogram, having the breadth of the vessel for its base, and the draught of water for its height, may be determined by dividing the number of horse-power of the engine by the cube of the required velocity, and multiplying the quotient by 7,26, or 6, as the vessel may require.

Hitherto the author's investigations have been confined to vessels moving in still water; he now proceeds to the consideration of vessels moving in rivers, in which case the velocity of the current must be taken into account; and also to the consideration of the effect, which is produced by causing the action of the engine to be applied to winding a rope round a roller, the outer end of the rope being attached to some fixed point, as

the shore. The results he deduces are as follow:—to stem a current with the least consumption of fuel, the absolute velocity of the vessel should be only equal to half the velocity of the stream. That the velocity resulting from the use of the rope and roller is greater than that which results from the use of the paddle-wheel in the proportion of the cube root of the velocity of the paddle to the cube root of the velocity communicated by the paddles to the vessel. That to enable the vessel to stem a current with an absolute velocity equal to half the velocity of the current, it requires three times the motive power, if that power acts on board the vessel, that would be necessary if the power were applied to the rope. That when the current is rapid, it is advantageous to use the rope for hauling, in order to stem it; but that if the current is not strong, it is preferable to use the paddles;—and that the paddles should always be used in descending a stream, when the absolute velocity of the vessel is greater than the velocity of paddles, or when the velocity of the stream is greater than the velocity with which the paddles strike the water, which will generally be the case.

In the part of the work dedicated to the description of the engines on board the different vessels, M. Marestier notices a high-pressure engine of Oliver Evans's construction, which is on board the Ætna, of Philadelphia, and his opinions appear favourable to the introduction of high-pressure steam for the purposes of navigation. He thinks, that with proper care in the construction of the engine and boiler, and caution in the subsequent attention which is paid, there would be but little risk of accident.

It cannot be doubted, that, on many accounts, the introduction of high-pressure steam for the purposes of navigation is desirable; the comparative lightness of the engines, the less consumption of fuel in some of them, and also their cheapness, must be considered as advantages; besides which there are many cases, especially in sea-going vessels, where the reserve of power possessed by the high-pressure engine would be highly valuable.

On the question of comparative safety, we must consider, that the greatest advocates for high-pressure steam always admit, that it would require care and caution on the part of those

entrusted with the management. So also does low-pressure steam. But in the low-pressure engine it is not to the interest of the engineer to raise his steam past a certain limit, for in that case he would over-work his condenser and air-pump, and lose instead of gaining power; while, on the contrary, in the high-pressure engine, there is no limit to the advantageous height to which the steam may be raised, but the strength of the materials to contain it; and it is in this difference, and the abuse which may arise from it, especially in steam boats, that the relative danger of the two systems lies.

M. Marestier has devoted several pages to a description of the different methods which have from time to time been proposed in America for substituting the use of oars, and he concludes his very able report of his researches with an Appendix, containing accounts of the American schooners, and of the machines used for clearing mud from their harbours, and for block and rope making, and several purposes connected with maritime affairs.

It appears that the account M. Marestier has given of the advantages resulting to America from the general adoption of steam navigation, has had due weight with the French government, as they have appropriated a considerable sum for the purpose of building steam boats; and there can be no doubt that in future wars great changes will be effected by the agency of steam.

We cannot better conclude this article than by a quotation from the report of the work, made to the Institute by Messrs. Sané, Biot, Poisson, and Charles Dupin: " Lorsqu'un nouveau genre de forces mécaniques s'introduit d'une manière utile dans quelque branche de l'industrie humaine, il donne au peuple qui s'en empare le premier, ou que l'exploite sur la plus grande échelle, un puissant moyen de supériorité sur les autres peuples. Souvent, enfin, le renversement des rapports de prospérité, de richesse et de puissance entre les nations, est la suite necessaire de l'adoption et du progrès des applications d'une espece nouvelle de forces mécaniques."

C.

ART. XXXV.—*On the Substitution of Mixed-metal Castings for Lead on the fore-side of the Knee, and under the fore-part of the Keel of Ships.*

(*To the Editor of Papers on Naval Architecture.*)

SIR,—Having had my attention frequently called to the state of the lead on the under-side of the keel, and fore-part of the knee of the head of ships, when brought into dock for examination or repair, I beg to offer the result of my observations on the subject.

It almost invariably happens that the lead below the water is very considerably fouler than other parts of the ship's bottom. In many instances I have seen great quantities (in some cases amounting to one or two ballast-baskets full) of testaceous animals, together with a variety of zoophitæ and algæ, collected on the lead, when the copper on the bottom has been almost free from them. The collection of these substances may probably be caused by the electro-chemical action, produced by the united metals and sea-water, which seems to effect a partial decomposition of the lead, and consequently to cause the surface of the lead to be rugged, to which these substances adhere. This foulness must be disadvantageous by impeding the velocity of the ship's motion.

It also frequently happens that the lead is worn through by the rubbing of the cables, particularly the chain cables. To prevent both these evils, I would recommend that the lead be substituted by mixed-metal castings, which would be little or no more liable to foul by its union with the copper than the copper itself, and which would effectually resist the rubbing of the chain cables, and at the same time would be less liable to be rubbed or beaten off by casualties. The advantage proposed by this substitution, is the prevention of the necessity of frequently shifting the lead as is now practised.

These castings for the under-part of the keel might be made in lengths of from four to five feet, and might be prepared for different classes of ships, and kept in store, so that they might

be fitted in a few hours. I would recommend that these castings be made in separate pieces for each side, turning up the usual distance on the sides of the keel, having a space between them under the keel, which must be covered with a strip of copper previously to bringing on these castings, which would overlap the copper, and whose edges should be rounded. The castings should be secured with screws. The after-pieces may be put on and secured first by removing one block, (which is easily effected by the present angular blocks of Sir R. Seppings,) the block being replaced when the after-pieces are complete. The next block may then be taken out, and the castings brought on in the same manner, shifting only one block at a time, which would supersede the present practice of being frequently obliged to suspend the fore-part of the ship for shifting the lead.

The castings to be fitted to the gripe and knee of the head would require a little more time, on account of the curvilinear form of the front; they would be screwed on as before, and would remain, when well fitted, many years, as it would not be necessary to take them off in the event of the copper being shifted, nothing more being required than to turn out the screws in the sides, (leaving those which would be in front,) and the edge of the copper sheets being placed under the lap of the castings, and the screws replaced, a close contact and good security would be effected.

This plan may at first be considered expensive, but if all circumstances attending the lead be taken into consideration, the superior advantage of this mode of fitting will, I trust, be obvious, and the expense ultimately considerably less.

I remain, Sir,

Your obedient Servant,

CHARLES WILLCOX.

H. M. Dock-Yard, Portsmouth,
Dec. 1st, 1826.

Art. XXXVI.—*Proposal for making Rudders of Metal.*

(*To the Editor of Papers on Naval Architecture.*)

Sir,—I beg to offer for insertion in the Papers on Naval Architecture, a proposal for substituting copper or mixed-metal rudders for the wooden rudders at present in use.

The advantages of such substitution I consider to be as follow:—

The great difficulty of procuring the main pieces of rudders, especially those for large ships, would be avoided.

The total expense of rudders would be diminished, taking the value of the materials when no longer serviceable as rudders into consideration.

The rudder-head might be made cylindrical, with a cast forward, which would admit of its working in a hole of the same size; a method at present partially adopted in wooden rudders, to prevent the sea forcing up through the rudder-hole, which the coating round rudder-heads, not made cylindrical, cannot effectually prevent. Procuring *timber* for the cylindrical heads of rudders, even of small ships, is very difficult, as the pieces require a considerable cast forward to prevent their being grain-cut. In metal this plan might be adopted without any difficulty.

The smallness of the head of the metal rudder would render it less liable to be struck by a shot in action.

The smallness of the head would also be very advantageous to the fittings of the circular sterns.

The metal rudder would possess the same advantage as the wooden one, of having the sole made independent, which in case of striking the ground might be carried away without injuring the main rudder.

I would also observe, that in the metal rudder an arrangement might be made for shipping a spare rudder-head, in case of the rudder-head being destroyed in action, by making the head separate from the main part of the rudder, so as to be shifted if necessary.

I shall be happy to submit for insertion in some future Number of your work, the plan for putting the metal rudder together, with the dimensions of the different parts for ships of all classes.—I am, Sir,

Your obedient Servant,

John Sheffield.

Portsmouth Yard, 18*th Dec.* 1826.

Art. XXXVII.—*Remarks on some part of "Naval Battles," by Charles Ekins, Rear Admiral, C. B., K. W. N.;* by Mr. J. Bennett.

Many of the senior members of the naval profession having been accustomed, during the protracted war, to the manœuvres of large fleets, practice has made comparatively easy to them, what observation, from almost childhood, rendered perfectly familiar. For several years past there has been no necessity for those numerous squadrons, which were formerly fitted out by the nation, so that our junior officers have not possessed the opportunities enjoyed by their seniors. Any means, therefore, which may be devised to compensate this disadvantage, is entitled to serious consideration. The first which would obviously occur is the study of works on naval tactics; these are all, more or less, founded on the excellent publication of Paul Hoste, printed in 1727; but this is become so exceedingly scarce, that it is rarely met with even in France. There is also great difficulty in procuring Clark's celebrated treatise: so that unless the English reader refers to the original works of M. de Morogues, Le Viscomte Grenier, and M. Bourdé de Ville-huet, he is obliged to consult the abridged and imperfect translations of these authors, published by Steel in his "Seamanship and Naval Tactics." A treatise on naval tactics, therefore, at the present time, appeared a desideratum, for the accomplishment of which we are indebted to the labours of a British Admiral, in writing a book for the express instruction of our young officers, many of the pages of which are devoted to a minute description of battles, which have shed a lustre on the naval glory of Great Britain.

It is possible for an experienced officer, forgetting when he was unacquainted with naval evolutions, and the difficulty he had in acquiring this knowledge, to consider the *theory* of naval tactics an unnecessary pursuit; and to bring forward the names of a Howe, a Rodney, and a Nelson, as instances of men unacquainted with it; but we too much respect the memory of these heroes to presume that they acted without fixed principles to guide them. Every other profession requires some years of application, and shall the naval be the only one in which it is needless? and if an officer is not to study seamanship and naval tactics, what is he to study? If it be answered, seamanship alone; it may be said, that a good seaman may be a bad tactician—he may be able to bring a single ship into action, but not a fleet. Though very far from supposing, as in the time of Elizabeth,[1] "a peculiar education no more necessary to enable a gentleman to assume the direction of a naval expedition than the command of a troop of horse;" or even that a La Hoste or a Clark, eminent theorists as they were, would be eligible persons to trust with such a responsibility; yet it may be fairly considered that theory admirably seconds practice,—that one individual may acquire from study a great portion of the information which another has derived from experience; and that supposing the practice of two commanders equal, the one who is acquainted with the theory of naval tactics is superior to the other if ignorant of it.

To men whose active pursuits render intense application usually impracticable, it is fortunate that naval tactics is not a difficult study; the rudiments of geometry, with which they are all familiar, are quite sufficient, with a few months attention, to render a person tolerably acquainted with the subject. After an elementary course, various methods will suggest themselves of giving more practical ideas; illustrations by a set of small models, as practised by Clark, will prove much more conclusive than diagrams on paper; after this, practice in boats will be of essential service. Admiral Ekins "acknowledges, with gratitude, the advantages he acquired by this practice when a midshipman in the Pearl frigate, com-

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[1] Aikin's Memoirs of Queen Elizabeth.

manded by the Honourable Seymour Finch. That excellent officer lost no opportunity of giving to the young men under his command all the instruction and experience in the various duties of a profession in which he was himself so perfect a master. At every convenient place and season, the boats (five) of his ship (and others when in company), well fitted for the purpose, with himself to direct, were exercised in the various manœuvres of a fleet. With a small set of numeral flags, a code of signals was formed, and in this manner were passed, with benefit and pleasure, many fine long evenings in some of the harbours of the Archipelago and Mediterranean, during the general peace which succeeded the first American war." But our large naval depôts might afford a still more excellent opportunity to junior officers of obtaining information. At Portsmouth, Plymouth, and Chatham, fifty or sixty harbour-boats may be collected, and manned by the young gentlemen of our navy, with an intelligent officer in each. Among that honourable class, the Post-Captains of our service, many would gladly volunteer their assistance in superintending this miniature fleet; and when the Midshipmen were fully conversant with the orders of sailing, and every manœuvre dependant on a change of wind, &c. they might have practical illustrations of our great naval actions; and, we would ask, what young officer, who studies the Battle of Trafalgar, when bearing down on the supposed enemy—who sees the ever-memorable signal hoisted, "England expects every man to do his duty"—who regards this victory either with respect to the ability with which it was planned and executed, the heroism and self-devotion manifested throughout it, or the consequences which resulted from it, but whose heart would thrill with veneration to the memory of a Nelson, and whose feelings would be excited to emulate so brilliant an example whenever his country may demand it? Or what veteran, when "fighting all his battles o'er again," but would feel a secret delight when the recollection of glorious days of past success was thus forcibly brought before him?

At the conclusion of these exercises, each Midshipman might be required to give diagrams of the various evolutions, with his opinion on their expediency, and he who displayed the

greatest ability might receive some honorary distinction, or be recommended to the notice of his superiors.

It has been before observed, that "Admiral Ekins's Naval Battles" is designed for the instruction of youth: as his Introduction does not contain any of the elementary principles of the science, a few leading observations will be given, which not being written by a professional man, are submitted with the greater deference to superior judgment.

It may be first observed, that the ultimate design of naval tactics is, to effect the greatest injury to an enemy with the least detriment to ourselves; and that system should of course be adopted which most effectually conduces to this end. One of the most obvious methods of succeeding in this, is by detaching a greater number of our own ships against a less number of the enemy's, and so separating them from their main body, that it may not be able to render them immediate support.

The object of the defence is to frustrate these intentions, and even, if practicable, to change the precaution of defensive measures into the assurance of formidable retaliation; from which it is evident, that among the many responsible qualifications a commander should possess, the foresight of discovering the operations of a designing enemy, and thereby preparing himself against every possible exigency, is not the least.

As simplicity in naval evolutions is of the most material consequence, and as fighting with advantage is the principal end of fleets, that order of sailing should be selected, when expecting an enemy, from which the order of battle can be most speedily formed; and the order of battle should be so disposed that the ships may be easily reunited if separated, that there may be good communication between the principal and subordinates, and that the ships may be enabled to render each other prompt assistance, by concentrating their forces, if required.

As the prospect of coming up with, and engaging an enemy, greatly depends on the properties of the ships, it is obvious, that with equal sailing qualities in the vessels, and equal skill in the officers (all other circumstances being the same), one ship can never come up with another, and that it will therefore

be in vain for an inferior sailing vessel to chase a superior one, unless she is better managed.—The same remark equally applies to fleets as to single ships.

In considering naval tactics *abstractedly, as a science,* we suppose every evolution to be made with mathematical precision, and each ship, both of our own and the enemy's, to sail equally well; and every movement of the ships, with the exertions of the officers and crews, to be under the sole direction of the chief; although it may frequently unavoidably happen that the commanders of divisions, and even of single ships, may be obliged to act on their own judgment and responsibility.

We are also to consider the probability of the success of an attack to depend on the ability displayed in its design, and not on the physical courage of either party, which we suppose the same; likewise that the adversary makes the best possible arrangements, under the circumstances in which he may be placed, showing equal judgment in frustrating the attack as was shown in designing it.

But when we take a more extended view of the subject, when we leave the speculations of the study for the consideration of the actual operation of hostile armaments, we shall find many other conditions will influence our determinations. The number, the qualities and situations of the ships, the enthusiasm and personal bravery of the officers and crews, their proficiency in the management of their ships and guns, their national character and prejudices, the intrepidity of their leader, and the confidence reposed in him, are all so many circumstances, which, as they act for or militate against a fleet, render its victory or defeat more or less certain. From hence we see why mere physical force is often rendered unavailing, and victory frequently obtained by the weak.

We remark once more, that the success of a plan is not always a just criterion of the policy which suggested it; absolute rashness may, by chance, fully succeed. On the contrary, the failure of an enterprise is not always a proof of its imbecility; the best concerted design may, from unforeseen events, totally fail. We may even venture to affirm, that in some cases, imbecility may be crowned with undeserved approbation; in

others, bravery may be loaded with unmerited reproach. We may find many examples in the history of our country, to convince us, that sudden storms and changes of wind, misconception of signals, an unfortunate shot from the enemy, circumstances over which we have no control, may prove insurmountable obstacles to success.

To return to the work before us.—It being impossible, within the limits of the present undertaking, to analyse all the valuable observations contained in the Naval Battles, a few of the articles only will be selected, which appear of general interest.

Several of the definitions are very good, and one of the most pleasing methods of elucidating them is chosen—examples from naval actions. There, however, appears an exception in the explanation of one of the most common sea phrases, ' abeam:" the words run thus; "abeam signifies the point at right angles with the main-mast of your ship." It certainly does signify this; but as *every point* in the horizon may be considered at right angles with the main-mast, which point is the uninitiated to choose? Perhaps the following definition may be less liable to misconception: any object is said to be abeam of a ship, when it is situated *in a line*, drawn through the main-mast at right angles with a fore and aft line.

The Introduction commences by pointing out, from Clark, page 27, a very common error, which is the supposition of a ship being near an enemy, and at the same time being exposed to the broadsides of several of his ships, ranged in line of battle. "If five ships are ranged in a line, the space between each 240 yards, and the length of each ship 40 yards, and the whole space between head and head of any two ships 28 yards," it is shown that a ship placed abreast of the enemy's centre ship must be at "least three cables length (720 yards) from it" before she can "be exposed to the fire of three ships in the enemy's line; and to bring the fire of five ships in the line of battle upon her, she must be at the distance of six cables length (1440 yards)."

As Admiral Ekins has omitted several other important observations, a few more extracts from Clark will be given. Having proved that the three centre ships of a line can but

just bring their broadsides to bear on the enemy's ship when at the distance of three cables, he adds—"She must be still less exposed at the distance of two cables (480 yards); and it will be almost impossible for the ships (on each side the centre) to touch her at 240 yards, or one cable's length distant. But as ships cannot well be kept in line of battle at a less allowance than one and a half cable's length asunder, it follows, that a ship must be at least 1080 yards distant before she can be annoyed by a cannonade from three ships extended in line of battle, and bearing upon her at the same time."

Mr. Clark very properly observes, that "ships in line of battle should never yaw, in order to bring their broadsides to bear on any, except the one immediately and closely opposed to them; as, in so doing, they would expose themselves to a raking fire from their opponents."

Clark's 4th section "of the principles necessary to be known for enabling us to judge of the different modes of bringing great fleets to action," is next discussed. Under this head Clark shows the disadvantages a windward fleet labours under, when either bearing down before the wind, or sailing in a "lasking" or oblique direction, to attack an enemy drawn up in line of battle to leeward, whose object is to avoid a general engagement. These disadvantages are pointed out by several plates, one of which is inserted in the work before us. It represents the windward fleet after having borne down on the enemy, drawn up in line of battle abreast of him; also showing every alternate ship of the enemy quitting the line to form another line to leeward, whilst the remainder keep up a continued fire, with the ultimate design of bearing away and joining their fellows to leeward. This recommendation of Clark to the leeward fleet, is disapproved of by Admiral Ekins, who points out, in a second figure, "the proceeding of the windward fleet in consequence," which he advises to "bear down, and pass through the enemy's line, rendered easily assailable by the absence of every alternate ship." This being a question which, in some degree, involves the principles of the celebrated Clark, it would be injustice to let it pass without entering a little more into its merits, first however premising, that in this discussion, Clark is not generally condemn-

ing the windward attack, but only the manner in which the supposed attack has been conducted.

The propriety of the attack from the windward is a question on which men of considerable professional attainments have differed. If the most ancient practice could alone decide the controversy, the advocates for the windward attack would unquestionably have the advantage; and there can be no doubt, setting aside its propriety or impropriety, that ancient prejudice handed down from generation to generation, was a great reason for its continuance. When the contest was decided by the sword, when vessels were armed in their bows and propelled by oars, two rival-squadrons would of course dispute the weather-gage, as the one who obtained it would, from the wind increasing its velocity, acquire greater momentum than its adversary, and come down upon him with a more violent shock. This was the case in the battles between the Romans and Carthaginians, in the Punic wars; between the Greeks and Persians, as at Actium and Salamis; and even as late as the year 1571, in the battle between the Christians and Turks, when a few guns only were used in the bows.

Taking a review of our naval engagements since the general use of cannon, we may trace three distinct periods or divisions in naval tactics. 1st. When squadrons acted collectively or simultaneously against each other, like battalions of infantry; 2nd. When each ship selected one of the enemy's for an opponent; and, 3rd. When a more powerful force was employed against a less powerful one, which is often effected by cutting off a few of the enemy's ships, either in the van or rear, and defeating them before the others can render them relief.

Our history is very barren of the particulars of naval combats before the actions of Matthews with Don Navarro, in the year 1744; but we have every reason to suppose that it was our policy, in the first two periods we have named, to attack from the windward if possible. In proof of this we may consult Paul Hoste, who, in describing the action between the English and Dutch, on the 7th August, 1653, says, "Les Anglois avoient essaié de gagner le vent: mais l'Amiral Tromp en aiant toujours conservé l'avantage, et s'etant rangé sur une ligne parallele à celle des Anglois, arriva sur eux, et commença

le combat avec tant de furie, qu'on vit bientôt plusieurs vaisseaux dématez, d'autres coulez bas, d'autres brulez," &c.

In another action between the English and the Dutch, in the Texel, 13th June, 1665, where the Duke of York, afterwards James the Second, commanded, it appears that the English had the weather-gage. The following quotation from Paul Hoste is interesting, as it shows that the present order of battle, on one of the close-hauled lines, was first put in practice by an English monarch, who, besides, attempted the manœuvre of breaking the enemy's line.[1] "Cet ordre (l'ordre de bataille) fut exactement gardé pour la premiere fois, dans le fameux combat du Texel, où le Duc d'Iork à présent Roy d'Angletterre défit les Holandois le 13 Juin l'an 1665, et c'est à sa Majesté Brittanique que nous en devons toute la perfection." After describing the numbers and situations of the two fleets, he thus proceeds: "Le Duc d'Iork s'etoit mis au corps de battaille, et il avoit donné son avant garde au Prince Robert, et au Comte de Sandvvich son arriere-garde. Le Sieur Opdam Amiral de Holande, s'étoit mis au milieu de son armée par le travers du Duc d'Iork, et il avoit opposé le Vice-Amiral Tromp, au Prince Robert. On se canona depuis trois heures du matin, jusques à onze, avec beaucoup de chaleur de part et d'autre, sans que la victoire se déclarât pour l'un ou pour l'autre partie. Les Holandois avoient pris un vaisseau

[1] That Clark, if the first who publicly recommended the breaking of the line in England, was not the original inventor, is evident from this action; and, if any thing further be wanted to prove it, the reader may refer to a chapter of Paul Hoste's, principally devoted to the various methods of cutting an enemy's line. (Evolutions Navales, p. 388.) But Clark's advocates have argued that it was not the merely cutting the line which was his object, but effecting it with a *superior* force: to these we recommend Paul Hoste's remark in p. 47, where he suggests that "Si l'armée qui est au-vent est plus nombreuse, elle peut faire un détachement qui venant fondre sur la queüe des ennemis, les met infailliblement en désordre." Mr. Clark must, therefore, have been mistaken when he says, that his mode of attack "is so far *new* as never to have been put in demonstration by writing, nor is there any example of its having been put in practice in actual combat." There cannot, however, be any doubt but that the idea was new to him. His book is written with such simplicity and ingenuousness, that we cannot for a moment suppose that he ever saw Paul Hoste's Traité des Evolutions Navales.

Anglois, qui par une bravoure temeraire voulut seul *traverser leur ligne:* mais aiant arrivé de temps en temps au Sud-Est, ils avoient marqué que le feu des Anglois leur faisoit de la peine," &c. &c.

Besides these two examples, we can easily prove that Paul Hoste and his contemporaries were in favour of the windward attack, for, after describing its advantages and defects, he says, p. 53: "On ne peut pas nier que les avantages d'une armée, qui est sous le vent ne soient aussi trés-grands, et il s'est même trouvé des gens qui ont crû que du moins il étoit aussi avantageux d'etre sous-le vent que d'etre au-vent. Mais je pense que si ou considére les choses avec un peu plus de soin, ou ne sera pas tout-à-fait de ce sentiment, et on trouvera que l'avantàge du vent est le plus grand de tous ceux qu'une armée peut souhaiter, soit qu'elle soit plus ou moins forte que l'ennemi. Je conviens qu'il est des cas extraordinaires, où il veut mieux être sous le vent; par exemple quand le vent est forcé, ou qu'il y a une grosse mer, quand ou se bat avec peu de vaisseaux, ou seul à seul. Mais encore, une fois, si deux armées nombreuses se battent d'un vent fait et maniable, celle qui est au-vent a' un tres-grand avantage sur l'autre."

Attention to the naval warfare of past years may enable us to form a better idea of the system of defence adopted, with little variation, by the French from the year 1744 to the year 1781, during which period are included the actions of Matthews, Byng, Keppel, Byron, Rodney, Graves, &c.; and on the propriety of which, at least as far as regards the two before mentioned diagrams, Mr. Clark and Admiral Ekins differ.

Mr. Clark, before illustrating his principles by a recital of the above actions as examples, expresses his ideas in the following energetic language: "If, then, after a proper examination of the late sea engagements, it shall be found that our enemy, the French, have never once shown a willingness to risk making the attack, but invariably have made choice of and courted a leeward position; if, invariably, when extended in line of battle, in that position they have disabled the British fleets in coming down to the attack; if, invariably, upon seeing the British fleet disabled, they have made sail and demolished the van in passing; if, invariably, upon feeling the effect of a

British fire, they have withdrawn at pleasure either a part or the whole of their fleet, and have formed a new line of battle to leeward: if the French have repeatedly done this upon every occasion: and, on the other hand, if the British, from an irresistible desire of making the attack, as constantly and uniformly have courted the windward position; if, uniformly and repeatedly, they have had their ships so disabled and separated by making the attack, that they have not once been able to bring them to close with, to follow up, or even to detain one ship of the enemy for a moment; shall we not have reason to believe that the French have adopted and put in execution some system which the British either have not discovered, or have not yet profited by the discovery?"

Or, in other words, Clark's advice to a windward fleet desirous of a close action, is, never to bear down before the wind on a leeward fleet, for, by so doing, your ships will be disabled, and you will be unable to follow the enemy, who will retire uninjured. His advice to the leeward fleet, wishing to avoid a general engagement, is, to suffer the enemy to bear down upon you, and, whilst he is so doing, to keep up a raking fire in his masts and rigging, which will necessarily disable several of his ships, yours remaining at the same time unhurt, as he can only bring his bow guns to oppose your broadside guns. If, notwithstanding the injury he has sustained, you perceive it is his intention to form into a line of battle; before his fire becomes serious, and during the confusion, let every alternate ship quit the line and retire to leeward, whilst the remainder form a check against the already crippled enemy, and at last make sail and demolish the enemy's van in passing to join your other ships, to form a new line to leeward.

Admiral Ekins's advice to the leeward fleet is directly contrary to the above, and amounts to this: not to allow every alternate ship to quit your line, for, by so doing, the windward fleet may bear down upon you, pass through the intervals of your broken line, and capture your remaining ships. Here Admiral Ekins takes for granted that the windward fleet is so uninjured that it is able to follow the adversary; "but (as Clark observes), by the supposition and demonstration, the ships of the windward squadron must be crippled and much

separated long before they can get to their station, therefore the van of the windward fleet must inevitably be exposed to the following movement, viz. that the leeward fleet perceiving the ships of the windward fleet in disorder, unsupported, and disabled from following him, will" (before the enemy can form himself into a formidable line of battle) "make sail, and discharge the fire of his whole line upon the adversary's van, ship by ship, as they pass in succession, and will form a new line to leeward, to be prepared if another attack shall be made upon them."

But the question does not rest here; we have still a further difficulty to solve; for Mr. Clark brings forward the unfortunate examples of Byng, Matthews, Graves, and many others, to prove, from sad experience, the accuracy of his principles; whilst those of Admiral Ekins are supported, with but little variation, by the brilliant example of Nelson, &c.

As there must be some cause for similar operations producing failure in one case and success in another, we will endeavour to reconcile these contradictory opinions, backed as they are by evidence so undeniable. To do which we must admit that, in the actions of Byng, Matthews, &c., the French officers and seamen were fully equal in ability and experience to ours, but that, in the time of Nelson, they were decidedly inferior to ours. Dupin even insists on the superiority of his nation in former times: we must allow something for national prejudices when he says, "Quoi qu'il en soit, à l'epoque dont nous parlons (1778), les éléments de notre armée navale étaient incontestablement supérieurs aux éléments, de l'armée Anglaise." But "lorsque la Revolution Française àrriva, la marine entiére fut dispersée; les officiers du plus grand nom périrent sur l'échafaud; la plupart des autres s'expatriérent, et le petit nombre qui resta ne put suffire pour conserver, et propager l'instruction dans toutes les parties du grand art de la marine. A cette époque orageuse qui souléva de la foule tous les grands hommes qu'elle n'engloutit pas, ou vit paraitre des marins pour qui la nature avait tout fait; mais un esprit de subversion, et de vertige fit élever à côté d'eux des êtres indignes d'un tel honneur: ceux-ci, par la médiocrité de leurs moyens; ceux-là, par la faiblesse de leur caractère; les derniers enfin, par la tur-

pitude de leurs principes. Quels furent les résultats d'un si monstrueux assemblage ? Des prodiges d'une valeur vraiment Française, ont été perdus pour notre gloire, parce que quelques ignorants ont erré, quelques lâches ont faibli dans les occasions décisives," &c.

He again observes, " Des 1778, nos armées navales étoient vraiment manœuvriéres ; elles manœuvraient trop peut-être et n'allaient pas toujours assez au but. Mais cela tenait aux idées militaires qui régnaient alors, au caractére de quelques chefs, et peut-être même à l'ésprit de notre ministére. Dans cette guerre, commes dans toutes nos guerres maritimes, *nous avons manqué d'un grand homme de mer*, ou bien nous lui avons manqué, en ne l'invetissant pas d'une grande, d'une absolue puissance, pour ramener la discipline et la victoire sous nos pavillons humiliés," &c.

These and similar reflections authorise us to conclude, that, in the supposed case, allowing the numbers and ability of the two fleets to be equal, Clark's proposals are to be preferred for the conduct of the leeward fleet ;[1] and that Admiral Ekins's recommendation to the windward fleet is only advisable when the enemy are decidedly your inferiors, in the ability of their officers, and the skill of their seamen. Moreover, when we refer to Nelson, as an example, we must allow, that in considering the measures of an extraordinary man, we are not to be guided by the limited notions we form of an ordinary character. His bold attempts would have failed, if executed with less than his own ability, or if seconded by officers and men of less intrepidity. No man ever possessed the requisites for an able commander in a more eminent degree than Nelson. Was the emergency great ? so was his invention ; was self-denial required ? he was the first to set the example. Clear-sighted in his views, prompt in his decisions, inflexible in his purposes, he inspired his friends with confidence, his foes with terror. He traced out to himself a glorious course, and finished his career by shedding his blood in the service of a country which has gratefully acknowledged his worth.

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[1] Still bearing in mind that the leeward fleet is desirous of avoiding a general engagement.

The mere accuracy of the detail of actions, although very desirable, is far from being the chief object of tactical descriptions. The errors and skill of Commanders should be pointed out, as shoals to avoid, or beacons to guide. It is still more desirable, that judicious recommendations should be given for regulating the conduct on similar occasions. In attending to this essential part of his work, Admiral Ekins is equally characterised for his modesty as an author and ability as a tactician. This we shall be able to show, by referring to his descriptions of some of our early actions with the French, selecting some of those which Clark has classed in his examples "of engagements, where the British fleets being to windward, by extending their line of battle, with a desire to stop, take, destroy, or disable the whole of the ships of the enemy's line to leeward, have been disabled before they could reach a situation from whence they could annoy the enemy; and on the other hand, where the French, perceiving the British ships in disorder, unsupported, and thus disabled, have made sail, and, after throwing in their whole fire upon the van of the British fleet, ship by ship, as passing in succession, have formed a line to leeward, to be prepared if another attack should be made."

In Byng's engagement with the French off Minorca, 20th of May, 1756, the British fleet weathered the enemy, and bore down on their opponents in an oblique direction; the van obeyed the signal by bearing away two points from the wind, each ship steering on her opposite in the enemy's line: the five headmost ships of the British line suffered considerable damage from the enemy's fire. "The fourth ship of the enemy's line bore away, then the fifth ship, then the two headmost, and after them the third ship followed their example; and lastly, the third ship astern of the French Admiral quitted the line and withdrew from battle. Meanwhile, the centre and rear of the French, perceiving this disorder in the British line, made sail, and with impunity threw in the fire of their whole line, each ship as she ranged past the van of the British, after which they bore away in succession to join their van, and formed a new line of battle to leeward."

Admiral Ekins describes, by a plate, a mode of attack, which, if it had been adopted by the unfortunate Byng, would most

probably very much have altered the consequences of the day. To explain this, we must observe, that the British fleet, about one o'clock in the afternoon, were upon the starboard tack, endeavouring to weather the French fleet on the larboard tack. When the British fleet had succeeded in their wishes, they (the British) tacked, and were on the same tack as the French. As was before observed, the British van bore away two points from the wind, and attacked the van of their opponents; as a means which would have prevented the disastrous effects which followed, Admiral Ekins proposes, not that the whole of our fleet should weather the whole of the enemy's, but that "the leading ship as she crosses the van of the enemy, followed by the others in succession, should bear up and break through the ships of the enemy's line, engaging them to leeward on the same tack; the first, second, third, &c. ships of our van, selecting the corresponding ships of the enemy's van as an opponent."

In Byron's battle off Grenada, July 6th, 1779, nearly the same effects followed as in Byng's action. We attacked from the windward, the French received us in their customary leeward position: our headmost ships, particularly the Grafton, Cornwall, and Lion, were crippled; those of the French received but little injury. In this engagement Admiral Byron had "the double object of securing an important fleet of transports, and of engaging an enemy's force of considerable superiority." Admiral Ekins's proposed mode of attack is for "the van and centre of the British fleet to keep their wind, (to prevent an attempt on the convoy,) while the rear, and perhaps part of the centre, carry a press of sail, and bring the rear of the enemy to close action before it can have time to form." An officer (a friend of Admiral Ekins') observes, "with British intrepidity this might have ended gloriously;" only, however, because the attack was to be made *before* the enemy had time to form, otherwise our rear might have suffered as much as our van did. Although the French had a favourable opportunity of cutting off our three disabled ships, and even of intercepting our transports, yet, as Clark observes, "as they did not think they could succeed in that attempt, without sustaining some damage, they, as usual, preferred a conduct more cautious, and kept their fleet entire, that the reduction of the Island of Gre-

nada, their particular object, might be carried on with the greater certainty of success."

The opinions, both of Mr. Clark and Admiral Ekins, are in general corroborated by a French officer, whose remarks are entitled to consideration, from his having been in ten naval actions. In describing this action between D'Estaing and Byron, he says,[1] "Il me semble que dans ce combat l'avant-garde française avoit généralement trop peu de voiles. Cela fut cause que l'arriére garde, obligée de combattre avec le grand hunier sur le mât, ne put jamais se développer, et finit par tomber sous le vent. Si l'avant garde avoit fait de la voile, elle auroit eu l'avantage de s'élever de plus en plus au vent des Anglais, ce qui l'auroit mise en position *de couper plus facilement les vaisseaux désemparés* et même de passer entre *leur convoie* et leur armée," &c.

Clark observes, that Admiral Arbuthnot's action with the French, off the mouth of the Chesapeak, 16th March, 1781, "is distinguished from the two former by a manœuvre peculiar to itself, and must be of some weight in support of what has been advanced with respect to French ideas. "For, quitting the windward situation, which they were possessed of, and assuming their post to leeward, they plainly showed that they were confident in their superior knowledge of naval tactics, that they relied on our want of penetration, and, getting to leeward, that they trusted our irresistible desire would hurry us on to make the customary attack, though at a disadvantage almost beyond the power of calculation; by which the British Admiral, having his ships crippled in the first onset, never after was able to close with, follow up, or even to detain a single ship." Admiral Ekins's proposed manœuvre is, "that the British fleet

[1] P. 384, "Cours Elementaire de Tactique Navale," by Audibert Ramatuelle."—Admiral Ekins observes that he has never examined this book; its perusal would afford the gallant Admiral, and every naval officer, both instruction and amusement; instruction, as the author's descriptions of our battles with the French display considerable professional intelligence; and amusement, from finding some extraordinary instances of French victories and English defeats never before known! This work notices, among several other naval engagements, the following: Byron, off Grenada; Arbuthnot and Graves, off the Chesapeak; Rodney and De Grasse, (12th April); Keppel and D'Orvilliers, off Ushant; Saumarez and Linois, off Cadiz; Parker and De la Motte, Barrington, off St. Lucia; the battle of the Nile, &c. &c.

should have carried a press of sail, to have intercepted the enemy and frustrated his intention. It is further proposed, that the British fleet should, when it approaches the enemy, invert the line; No. 1 stopping at No. 1 of the enemy; No. 2 passing close to leeward and fixing upon No. 2 of the enemy's line, and so of the rest."—As a modification of Admiral Ekins's proposition, each ship of the enemy might have been exposed to the fire of two ships, by the first ship of our fleet placing itself on the windward side of the enemy's first ship, whilst our second ship placed itself on its leeward side; the third and fourth ship adopting the same plan with the second ship of the enemy, &c. They would then have been placed in a similar situation to some of the French fleet at the battle of the Nile, and we might at least have anticipated the capture of each of the enemy's ships, which was attacked by two of ours.

The last action, which will be selected as a further illustration of the ill effects, arising from the plan adopted by the British in the windward attack, is that of Admiral Graves with the French, off the Chesapeak, 5th September, 1781: "the French were at anchor across the entrance of the Chesapeak, from Cape Henry to the middle ground, who, as soon as they perceived the British fleet approaching, (on the starboard tack,) got under sail, and stretched out to sea upon the larboard tack. Each fleet stood on some time; when the British passed the French fleet, they (the British) wore on the other tack, nearly parallel to the enemy, and when the British van was abreast of the French van, they (the British) bore down on the enemy, and thus exposed themselves to be raked." Now had Admiral Graves stood on in the same direction, that is, nearly parallel to the enemy, he would have opposed broadside to broadside, and been at least on equal terms with his adversary. This would have been far preferable to the plan which the English Commander adopted. But it would perhaps have been still more advisable to have adopted the suggestion of Admiral Ekins (p. 124): "It is here with deference submitted, that the signal at this time (when the enemy's ships hove in sight at anchor) should have been for a *general chase;* then to clear for action, and to engage the enemy on arriving up with them. By these measures the headmost of the British fleet would most

likely have brought to close action the most advanced of the enemy, and have thrown the rest, not yet under way, into disorder. The British ships as they drew near to the leading ships of the enemy should wear and close with them (either to windward or to leeward) on the same tack, and the remainder following in close succession, a desperate attack might have been made upon their van, at that time beyond the reach of assistance from their rear, unable to clear the anchorage, and not in a situation to form in line for a regular defence." This proposition is characterised by a contempt for all the finesse of the art; displaying a daring intrepidity which must inevitably have produced a decisive result. The enemy were in disorder, entangled amidst shoals, and a general action, always desired by us, and avoided by the enemy, must have been the consequence. As it was, the van of our fleet got considerable damage from the raking fire of the enemy. "Rear-Admiral Drake shifted his flag into the Alcide until the Princess got up another main-top-mast. The Shrewsbury, whose Captain lost a leg, and had the first Lieutenant killed, was obliged to shift both top-masts and top-sail-yards, and had sustained very great damage. Captain Colpoys, of the Orpheus, was ordered to take command of her, and put her in a state for action. The Intrepid had both top-sail-yards shot down, her top-masts in great danger of falling, &c. The Montague was in great danger of losing her masts; the Terrible so leaky as to keep all her pumps going; and the Ajax was also very leaky." The author of "Cours Elémentaire de Tactique Navale," after rather an exaggerated account of the success of the French against the English in this and other actions, thus proceeds, (page 363,) "La consérvation de l'ile de la Grenade, la réduction d'Yorck-Town, où l'armée Anglaise se rendit prisonniére, la conquête de l'ile Saint Christophe, et des dépendances, ont été le resultats de grands combats, où l'on a laissé l'ennemi faire tranquillement sa retraite, pour ne pas s'exposer à lui laisser la faculté de jeter des sécours dans les points attaqués."

It is worthy of remark, that neither in the action of Byng, Byron, Arbuthnot, or Graves, has Admiral Ekins recommended the windward fleet to fill up the intervals left by the alternate ships of the leeward fleet, when they quitted their first position

to form another line of battle to leeward, although he recommended it in the supposed case before discussed.

We conclude this part of the subject by observing, that it is scarcely possible, under any circumstances, to suggest an attack in such a manner as to preclude a determined enemy from making a formidable defence; this might have happened had the excellent hints given by Admiral Ekins to the British been adopted in these four engagements. But this is no argument against the propriety of his hints, for had the enemy retaliated by bringing their van to support their rear, or their rear to support their van and centre, as the case may be, a general action, which was always our aim, must have been the consequence.

The importance of chasing and retreating in good order is too obvious to be insisted on. In describing these operations of a fleet, Admiral Ekins has selected the remarkable retreat of Admiral Cornwallis, who with five line of battle ships and a frigate effected his escape, and bid defiance to thirteen ships of the line, fourteen frigates, two brigs, and a cutter. This was such an extraordinary instance of resolution and skill, that both Houses of Parliament voted their unanimous thanks to Admiral Cornwallis and his companions. It will not be necessary to enter farther into the particulars of this retreat, which, without detracting from the bravery of the English, rather displays the indecision of the French, than to observe, (Naval Battles, page 209,) "the British Admiral probably formed his little force into *one* of the angles of retreat, the flag-ship at the angular point," and *a-head*. Whether they were or were not formed in this manner (which Admiral Ekins himself rather doubts, and which is decidedly contradicted in James's Naval History,) is immaterial to the present purpose; what we have to observe is, that the author of Naval Battles has rather mistaken the opinions of Paul Hoste, on whom he appears to found his representation of there being *two* angles of retreat, by observing, (page 219,) "the orders have since been discovered in 'L'Art des Armées Navâles, derniere partie,' (page 402)." And again, (page 221,) "both these orders are to be found in Paul Hoste, Plates cxxviii., cxxix., pages 402, 405."

In Plate xiii., Part II., Admiral Ekins gives two diagrams, each explanatory of an order of retreat. The first represents

a fleet ranged on the two close-hauled lines, forming two of the sides of an isosceles triangle, in the vertex of which is placed the Admiral, being *ahead* and to *leeward;* a line joining the rear ship of each division constitutes the third side of the triangle; the ships are sailing before the wind. The second figure is precisely the reverse of the first; that is, the vertex of the triangle, in which the Admiral is placed, is *astern* and to *windward.* It will be our object to prove that the *second* figure only is authorised by Paul Hoste for the retreat of a fleet; and that he proposes the first, not as an order of retreat, but as an order of sailing.

Paul Hoste first alludes to the order of retreat in page 90, and observes, that "When a fleet is obliged to retreat in sight of an enemy, we range it on the obtuse angle. The Admiral is in the middle and to windward; the division of the fleet to the left of the Admiral, is placed on the starboard line of bearing, and the other division on the larboard line of bearing. The fire-ships and store-ships are in the middle," and to *leeward.* "This method of arranging a fleet when retreating, appears to me to be very good, because the enemy cannot approach the fugitives without exposing themselves to the fire of the windward vessels. Thus the enemy's ships cannot approach the ships in the wing without being exposed to the fire of the Admiral's ship. If it is thought that the fleet is too much extended in this order, the two wings may be contracted; by this means the fleet will assume the form of a half-moon, in the middle of which a convoy would be securely situated." Nothing can be more clear than the above; the ships are to be ranged on the two close-hauled lines, the Admiral being to windward and *astern,* the convoy, if any, to be placed to leeward. It will be perceived that this order agrees with Admiral Ekins's second figure, and is the reverse of the position assumed by Cornwallis. (See Naval Battles, Part ii., Plate ix.)

By referring to Paul Hoste, pages 402, 405, plates cxxviii, cxxix, we find him discussing the best situation for fire-ships, store-ships, or a convoy of any description. The subject is considered in two points of view—1st. The stations of fire-ships, &c. in the orders of sailing. 2nd. Their stations in the

order of retreat. "In all the orders of sailing, the fire-ships, &c. are to windward: we adopt this plan for several reasons— 1st. That this sort of vessels are in less danger of being taken, as they can seek protection (the wind abaft) in the middle of the fleet; 2nd. That they may conveniently approach the commander's when necessary; 3rd. That they may not be delayed by the rest of the fleet, as they can sail better free than close hauled." These observations are elucidated by three figures; the 1st (Plate cxxviii.) represents a fleet in the first order of sailing, on one of the close hauled lines, with the convoy to windward. The 2nd represents a fleet in the third order of sailing, on the two close hauled lines; the Admiral is ahead and to leeward, the convoy, as before, being to windward: this order agrees with Admiral Ekins's first figure. But we cannot suppose that the learned Jesuit intended this for an order of retreat, for he has before remarked, that, in the order of retreat, the convoy should be placed to leeward, whereas, in this figure, they are placed to windward, corresponding with our former quotation, that "in all the orders of sailing the fire-ships, &c. are to windward." Plate cxxix. also contains two figures; the first represents a fleet in the fourth order of sailing: it is divided into three squadrons, with their respective commanders ahead, and to leeward of the two columns which compose their squadron; the convoy still to windward. Paul Hoste has omitted showing the stations of a convoy in the second order of sailing (on a line perpendicular to the wind), and likewise in the fifth order of sailing (where the fleet is divided into three columns, each column being parallel to one of the close hauled lines); either from considering the subject sufficiently explained, by his delineations of the first, third, and fourth orders, or else from not thinking the second and fifth orders of sailing so applicable to the purpose. The second figure in Plate cxxix. merely represents a fleet in the order of retreat, as before described, with the Admiral astern and to windward, and the convoy to leeward. We may remark that, in Paul Hoste's order of retreat, the convoy is placed in the middle of the fleet, between the two wings; whereas this cannot be done in Admiral Ekins's first figure, as they would

be immediately exposed to the fire of the enemy; to prevent this, in the retreat of Cornwallis, the two frigates are stationed outside the fleet, and to leeward. (Naval Battles, Plate ix. Part 11.)

It becomes another question whether it would not be as advantageous for a fleet to retreat in the order of Figure 1 as in that of Figure 2 (Naval Battles, Plate xiii.), which is proposed by Paul Hoste. The following considerations, among others, may serve to determine it: Which least impedes the progress of a fleet? Which will most annoy the enemy? Which will most effectually protect a convoy? And if, after every exertion, an engagement is unavoidable, Which can be most readily formed into a line of battle?

But it must be allowed that, in the retreat of a fleet, as in almost every naval evolution, a commander must be guided by circumstances. If he has a convoy under his protection; if he feels it his duty to sacrifice himself to ensure its escape; if he is more or less numerous than the enemy; if his ships are superior or inferior sailers; if he can foresee a change of wind from local situation; all these, and even the order adopted by the pursuing enemy, must influence him in his determinations either to retreat on the two close hauled lines, on one of the close hauled lines, on a line perpendicular to the wind, in two divisions, or perhaps without any order at all, each ship escaping in the best manner she can.

It is readily granted that the present sketch has done the gallant Admiral but little justice, and affords but a very imperfect idea of the contents of his work. It would have been interesting to have followed him through his excellent tactical descriptions of actions of unparalleled success to the British arms; but this, if ever undertaken, must be deferred to a future period.

Admiral Ekins apologises for the defective arrangement of his work by observing, that "much of the information and remarks coming from different quarters, and at different times, for which the writer is so greatly indebted to others, has been introduced without that strict regard to arrangement which is so desirable; much indeed has been done to lessen this defect, and for any

which may remain, he must rely upon the candour and forbearance of the public to forgive;" and we feel persuaded that this appeal will not be made in vain. If forbearance should be yielded to any class of men it is to the naval profession: however, if sound sense and judicious observations be a sufficient apology for defective arrangement, the gallant Admiral may in very many instances claim it.

We might surely have a book in our language which should supersede the necessity of our young officers studying translations from the French. The writer of the present Paper cannot yield his consent to the unqualified approbation of Admiral Ekins of 'Steel's Treatise on Seamanship and Naval Tactics;" this abridgment and translation are not executed with judgment; there are even errors pointed out in the errata of the originals which are not rectified in the translation. If another edition of the 'Naval Battles' be required, the last part might be perhaps advantageously placed first, prefaced by definitions, general principles, and a description of all the orders of sailing, of retreat, of battle, &c., with the various evolutions dependent on changes of wind, &c.; the other portions might be classified under different heads, something similar to 'Clark's Treatise'; by this means the 'Naval Battles' would form an elementary treatise, which would enable the student to become acquainted with the subject of Naval Tactics without the necessity of refering to other works.

The Appendix contains an account of the round sterns lately introduced into H. M. ships by Sir Robert Seppings, with a comparison between those of Sir Robert and those of Mr. Roberts. In this part of the book I consider the gallant Admiral has been less successful than in his account of naval actions. I will not, however, anticipate the subject, as it will afford ample matter for a future Paper in this work.

PAPERS

ON

NAVAL ARCHITECTURE,

&c.

Art. XXXVIII.—*The Method adopted in the Swedish Navy for calculating the lengths and diameters of the Masts and Spars for all Frigate-rigged Ships. Communicated by* Lieutenant A. G. Carlsund, *of the Swedish Royal Naval Engineers.*

The following formulæ for calculating the lengths of the masts and spars were deduced by Lieutenant-Colonel Ringheim of the Naval Engineers, from calculations which he made on a very large number of vessels; they may therefore be said to be the results of experience; and it will also be seen that they are founded on those elements of the construction of a ship, which have the greatest influence on her stability. These formulæ have been used in Sweden during the last ten years, for determining the sails for frigates and smaller vessels, but for those for line-of-battle ships the method recommended in Chapman's "Treatise on the Area of Sails" is adhered to; the centre of gravity of the ship being either calculated, or approximated to by actual experiment.

The formulæ for calculating the diameters, the lengths being given, were determined by Chapman. It will be seen that the diameters of the yards are deduced from their lengths only, while those of the masts depend on the lengths of the mast and yard, that is, on the size of the sail.

These rules for fixing the diameters of the masts and spars, are only applicable for the species of wood used in Sweden for mast making, which is the best Riga; but of course, if the co-

efficients are altered in proportion to the difference in the strength of the species used in any other country, the rules may be made equally applicable.

In order to determine the formulæ for calculating the lengths of the masts and spars:

Let the length between the rabbets on the load-water line = L.

The moulded breadth = B.

The draught of water at the midship section, from the load-water line to the upper edge of the rabbet = d.

The depth of the centre of gravity of the displacement, below the water-line = c.

All these dimensions being in Swedish feet, then the moment of the sails is $= \dfrac{2.0755\sqrt{d^3}}{c} \times \overline{B^2 L}\,\big|^{.8717}$

The sails included in this moment are,—the main and fore courses, the three top-sails, the three top-gallant sails, the fore-top-mast stay-sail, jib, and driver.

The mizen top-sail and the top-gallant sails are calculated to their proper form: that is, hollowed at the foot to an arc of a circle.

If the cube root of this moment be extracted, and represented by R, we have:

The length of the main-mast from the load-water-line to the upper side of the trestle-trees, measured in a perpendicular direction = 0,6711 R.

The length of the main top-mast from the lower part of the fid-hole to the upper side of the top-mast trestle-trees = 0,4593 R = S.

The length of the main-top-gallant mast between the similar points = 0,2694 R = T.

The head of the main mast = 0,27 S.

The length of the main top-mast head above the trestle-trees = 0,25 T.

The distance between the main course and the main top-sail = 0,05 S.

The distance of the lower edge of the main top-sail, below the upper side of the main trestle-trees = 0,18 S.

The distance between the main top-sail and the main top-gallant sail = 0,07 T. and the width of the main top-sail at the lower edge = 0,7301 R = B.′

The width of the main top-gallant sail at the upper edge = 0,3544 R. The sides of the top-sails and top-gallant sails form a straight line; this will give the breadth of the top-sail at the upper edge, which call = C.

The head of the fore-mast is below the main-mast head, 0,4 of the length of the head of the main-mast; and its sails, &c. are $\frac{88}{100}$ of the sails of the main-mast.

The head of the mizen-mast is below the head of the main-mast, $1\frac{1}{2}$ the length of the head of the main-mast, the rest of the sails, &c. of the mizen mast are $\frac{72}{100}$ of the sails of the main mast.

The distance the upper edge of the main top-gallant sail is below the upper side of the framing of the top-gallant mast, = 0,144 T.

The distance of the upper edge of the main top-sail below the upper side of the trestle-trees is = 0,128 S.

The length of the main top-sail yard-arms is $= \frac{B'-C}{3}$

The main and fore yard-arms, and all three top-gallant yard-arms, are $\frac{1}{18}$ the width of the sail.

The distance the main royal-sail is above the shrouds, = 0,546 T.

The width of the driver at the lower edge = 0,75 B′, and at the upper edge = 0,472 B′.

The perpendicular distance from the centre of the fore-mast to the tack of the fore-top-mast stay-sail = 0,764 B′. The length in the direction of the stay = 0,818 B′. The perpendicular height from the sheet corner = 0,324 B′.

The perpendicular distance from the centre of the fore-mast to the jib tack = 1,03 B′. The length in the direction of the stay = 1,00 B′. The perpendicular height from the sheet corner = 0,446 B′.

The diameters of the masts and spars are in proportion to some power of the length.

Suppose L the length of the yard, the arms not included, then for all ships and frigates, the diameters of the main and fore-yards

$$= \frac{L^{\frac{11}{10}}}{5.985} \text{ in inches}$$

For top-sail and mizen yards $= \dfrac{L^{1.1}}{6.525}$

Top-gallant-sail yards - $= \dfrac{L^{1.1}}{7.56}$

Royal yards - - - - $= \dfrac{L^{1.1}}{8.1}$

Now, suppose $S =$ length of the top-mast between the upper sides of the upper and lower trestle-trees, and $R =$ length of the top-sail yard, the arms not included.

Then the diameter of the topmast $= \left(\dfrac{RS}{4.777}\right)^{\frac{11}{20}}$ in inches.

Now, let $M =$ length of the mast from the water-line to the upper side of the trestle-trees,

$L =$ length of the main, fore, or mizen yard, the arms not included. Then the diameter of the mast $= \left(\dfrac{MLSR}{3.236}\right)^{\frac{11}{40}}$

All the diameters, obtained by these rules, are in inches, when the lengths are in feet. All the dimensions of masts and yards are proportioned according to these rules; the yards are then tapered towards the ends, in the common way, by describing a quadrant with a radius equal to half the larger diameter, and taking equidistant ordinates in this quadrant for measures of the diameters of equidistant places on the yards. But when (as has been the case for two years) the yards are formed after a cubic parabola, $\frac{3}{40}$ part of the thickness obtained by the above rules is added, and the resulting middle diameter, if put $= a$, gives the diameter at every $\frac{1}{8}$ part of the length from the middle; viz., the middle $= a$; the first part $= 0.966\ a$; the second $= 0.9086\ a$; the third, $0.855\ a$; the fourth, $0.7937\,a$; the fifth, $0.7211\,a$; the sixth, $0.6300\ a$; the seventh, $0.5200\ a$; the eighth, or outer end, $0.3900\ a$.

The weight of this yard is the same as its weight on the old plan, and the strength is nearly $\frac{1}{4}$ more.

To adapt these formulæ to any other measure than the Swedish, there must be an alteration in the co-efficients.

First, suppose $b = a\,Q^x$, which is an equation of a similar form, and suppose b and Q to become b' and Q',

$$b' \text{ being } = n\,b,\ n^2\,b, \text{ or } n^3\,b, \text{ \&c. \&c.}$$

$$\text{and } Q' = n\,Q,\ n^2\,Q, \text{ or } n^3\,Q, \text{ \&c. \&c.}$$

the exponents depending on the form of Q.

Then, applying the formulæ to another measure, the equation $b' = a'\,Q'^x$ must be true,

$$\text{or } n\,b = a'\,\overline{n\,Q}|^x \quad - - - - - - - - - - \quad (1)$$

$$a' = \frac{b}{n^{x-1}\,Q^x}$$

$$\text{But as } b = a\,Q^x$$

$$a' = \frac{a}{n^{x-1}}$$

If Q consists of two factors, each varying in the same proportion with n,

$$\text{from (1)} \quad n^2\,b = a'\,\overline{n^2\,Q}|^x$$

$$a' = \frac{b}{n^{2x-1}}$$

$$\text{or generally } a' = \frac{a}{n^{rx-1}}$$

If b and Q do not alter in the same ratio, let m and n represent their ratios to the measure in which the formula is calculated; and hence, if v and r are the simultaneous exponents of m and n,

$$m^v\,b = a'\ \overline{n^r\,Q}|^x$$

$$a' = \frac{m^v\,b}{n^{rx}\ Q^x}$$

$$\text{but } b = a\,Q^x$$

$$\therefore\ a' = \frac{a\,m^v}{n^{rx}}$$

This latter expression is applicable, when the measures of the two countries are not equally subdivided.

Art. XXXIX.—*A Continuation of the Abbé Bossut's Report on the Experiments on the Resistances of Fluids, which were made by M. D'Alembert, the Marquis De Condorcet, and the Abbé Bossut.* (From page 194.)

The following table shows the relation between the resistances according to the theory, and those deduced from the experiments, for the same surface moved with different velocities, in a fluid of infinite extent.

Distinguishing Number of the Vessel.	Number of the Experiment.	Time occupied in passing through the last 20 feet.	Moving Weight calculated by the Theory.	Moving Weight shown by the Experiment.
		Half Seconds.	Marcs.	Marcs.
No. 21.	1	36,00	16..base	16
	2	32,50	19,63	20
	3	26,50	29,53	30
	4	23,50	37,54	40
	5	21,00	47,02	50
	6	19,45	54,81	60
	7	18,00	64,00	70
No. 22.	8	30,00	16..base	16
	9	25,50	22,15	24
	10	22,30	28,96	32
	11	20,00	36,00	40
	12	18,15	43,72	48
	13	16,55	52,57	56
	14	15,55	59,55	64

It is evident, from the two preceding Tables, that the resistances experienced by a surface moved with different velocities in an indefinite fluid, vary nearly as the squares of the velocities, this law will apply both for the direct resistances and for the oblique; but it must be observed that, strictly speaking, the resistance increases faster than the square of the velocity, and the reason for this is easily explained: for as soon as the floating body is in motion, the fluid is divided and displaced; but as this cannot instantaneously be effected, at the commencement of the motion the velocity is gradually accelerated; while it is small, the water is easily displaced, and escapes along the sides of the vessel, so that its surface remains level; but as the

velocity increases, there is more difficulty in displacing the fluid; which consequently accumulates before the bow, and forms a sort of bow of fluid, which is of more or less extent in proportion as the velocity is great or small, and also of course in proportion to the size of the solid bow. Also the fluid sinks towards the aft part of the vessel; this double effect is the greatest, every thing else being constant, when the velocity is the greatest. Therefore the increase of velocity augments the difficulty a vessel experiences in dividing a fluid.

It is the same in the resistances experienced by bodies moving in fluids either wholly or partly immersed. Thus, for example, the resistance experienced by a cannon-ball in passing through the air, must increase in a greater proportion than the square of the velocity. In fact, the greater the velocity, the greater is the difficulty which the displaced air has to overcome in escaping round the sides, so as to fill the vacuum left behind the ball.

Section 2.—*Whether the Direct or Perpendicular Resistances, the Velocity being the same, are in proportion to the Surfaces.*

Let P and P′ be the direct resistances, whether absolute or relative, experienced by the planes A and B, which move with the uniform velocities v and u, then, according to theory, $P : P' :: Av^2 : Bu^2$. Now, by supposing that there is but little difference between the velocities v and u, it follows from the preceding article that the relation of v^2 to u^2 may be considered exactly as that of the resistances.

Consequently it may be concluded that, with the same velocity, the planes A and B will experience resistances which will be in proportion or not in proportion to their areas, according as experiment shows that the proportion $P : P' :: Av^2 : Bu^2$ exists or not.

There are two distinct cases to be considered in this investigation: the first is,—that in which the two planes opposed to the fluid are equally immersed; and the second is,—that in which the immersions are different; for the law of the resistances may not be the same for two surfaces which differ in breadth as for two which differ in depth.

Case the first, in which the depths of the immersed surfaces are equal, or nearly so :—

We will compare the resistance of the vessel No. 1 with that of No. 2, and also with that of No. 3, when to its second draught of water, here the two velocities v and u, always taken from the last twenty feet, differ very slightly; also the depths in the water of Nos. 1 and 2 are the same, being each one foot; the surfaces differ only in breadth, that of the first being half that of the second. With regard to the depths in the water of Nos. 1 and 3, there is a slight difference, the first being twelve inches, and the second twelve inches and five and a half lines; the breadth of the surfaces are to each other in the proportion of 144 to 236, and consequently the surfaces are to each other in the proportion of 1 to 1,7015 nearly. The difference in the depths of Nos. 1 and 3 is too small to have any sensible effect in the proportion of the resistances to each other, even supposing that, every thing else remaining the same, the resistance to a plane surface varied in proportion to its greater or less depth in the fluid.

The following Table is formed from the experiments of Chapter 2d. The first column contains the numbers of the vessels; the second contains the numbers of the corresponding experiments; the third shows the comparative times of describing the last twenty feet; the fourth shows the weight which it should require to move the second-named boat, under the supposition that the weight required to move the first-named boat has been determined by experiment, and that the proportion $P : P' :: Av^2 : Bu^2$ exists: and the last column shows the weight which it actually required to move the second boat.

Relation between the direct Resistances, experienced by Surfaces immersed to equal or nearly equal Depths in the Fluid.

Distinguishing Numbers of the Vessels Compared.	Experiments Compared.	Comparative Times of passing through the last 20 Feet.	Weight Calculated by the Theory.	Weight shewn by the Experiment.
		Half Seconds.	Marcs.	Marcs.
Numbers 1 and 2.	1 and 10	17,08 17,32	23,33	24
	2 and 11	15,90 16,12	27,24	28
	3 and 12	14,84 15,12	30,83	32
	4 and 13	14,00 14,19	35,04	36
	5 and 14	13,50 13,68	38,95	40
	6 and 15	12,75 13,25	40,74	44
	7 and 16	12,45 12,59	46,93	48
Number 1, and Number 2 to its second Draught of Water.	1 and 35	17,08 17,19	20,15	22
	2 and 37	15,90 15,80	24,12	25
	3 and 39	14,84 14,88	27,08	28
	4 and 40	14,00 14,19	29,81	30
	5 and 41	13,50 13,80	32,56	32
	6 and 43	12,75 13,00	36,01	38

This Table shows that for surfaces which vary in breadth, but are immersed to equal depths in a fluid, the resistance, under the same velocity, is nearly proportional to the areas immersed at the commencement of the motion. We say nearly, because, in fact, the resistance increases in a rather greater proportion than the areas of the surfaces. It is evident this would be the case, for, the greater the surface is, the greater difficulty must the fluid which is forced before it experience in escaping and recovering its level.

It has been already remarked, that there is not only a rising of the fluid before the bows of the vessel, but a depression towards the after parts, which causes a difference in the level of the fluid from the fore to the after part of the vessel. If the proportion between the elevation and depression were known, the surface which the body presents to the action of the fluid would be known; and it might then be determined whether every thing else remaining the same, the resistances follow the proportion of the surfaces. But this cannot be strictly ascertained: it depends on the surface and form of the bow, and on that of the stern, on the length of the vessel, and more particularly on the velocity. These various elements render its determination too difficult; it can only be observed generally, that the depression may be at the most equal to the elevation, and that generally it should be less.

Suppose, for example, that in the experiments in the preceding Table, the depression is two-thirds of the elevation. It is evident that, in respect to the resistance, the vessel is under the same circumstances as if the elevation were five-thirds of that which was observed. If, therefore, the heights of the risings thus corrected be considered as making part of the heights of the surfaces presented to the fluid, the following Table will be formed, which is nothing more than the former one with the column of the times suppressed, and a column containing the resistances, calculated with reference to this rising, added.

These calculations are only given as hypothetical, but, considering the elements on which they are founded, they cannot be far from correct.

Distinguishing Numbers of the Vessels Compared.	Experiments Compared.	Weight calculated, without taking into considera-tion the rising.	Weight calculated, taking the rising into consideration.	Weight shown by the Experiment.
		Marcs.	Marcs.	Marcs.
Nos. 1 and 2.	1 and 10	23,33	24,19	24
	2 and 11	27,24	28,23	28
	3 and 12	30,83	31,76	32
	4 and 13	35,04	....	36
	5 and 14	38,95	39,73	40
	6 and 15	40,74	41,54	44
	7 and 16	46,93	....	48
No. 1 and No. 3 to its Second Draught of Water.	1 and 35	20,15	19,69	22
	2 and 37	24,12	23,77	25
	3 and 39	27,08	26,93	28
	4 and 40	29,81	....	30
	5 and 41	32,56	31,05	32
	6 and 43	36,01	35,52	38

It is evident, from the first part of the above Table, that by estimating the rising in the proposed manner, the calculated resistances approach very nearly to those found by experiment. They would agree more nearly, if the depression of the water at the stern were to be taken equal to three-fourths of the elevation of the water at the bows. The second part of the Table does not give precisely similar results; but when we consider how easily an error of several lines may be made in observing the height of the rising, and that the difference in the level of the water varies with the form of the vessel, the velocity remaining the same, one would be inclined to believe that if the risings were correctly observed and noted in the Table, the conclusion would be, that the resistances might be considered as in proportion to the surfaces. But it must be observed, that as the risings of the fluid depend on the velocities, the relation of the resistances will differ from that of the surfaces, if the velocities differ in any considerable degree.

Case the second:—When the depths of the surfaces immersed in the fluid are different.

The vessel No. 3 having three lines of floatation, furnishes us with three surfaces having the same breadth, and differing only in their depths. The three surfaces immersed in the fluid

are to each other as the numbers 940, 1495, 1900. The resistances experienced by them have been calculated, and are shown in the following Table. In each comparison, the velocities differ almost imperceptibly.

Relation between the Direct Resistances experienced by Surfaces immersed to unequal Depths in the Fluid.

Distinguishing Numbers of the Vessels Compared.	Experiments Compared.	Times of Describing the last 20 Feet.	Weight Calculated by Theory.	Weight shown by Experiment.
		Half Seconds.	Marcs.	Marcs.
Number 3 First and Third Draughts of Water.	17 and 44	20,05 / 19,60	21,15	20
	18 and 45	18,39 / 18,07	25,12	24
	19 and 46	17,37 / 16,88	29,96	28
	20 and 47	16,32 / 15,88	34,15	32
	21 and 48	15,30 / 14,69	39,47	36
	22 and 49	14,50 / 14,00	43,37	40
	23 and 50	14,00 / 13,67	46,64	44
	24 and 51	13,47 / 13,25	50,24	48
Number 3 First and Second Draughts of Water.	17 and 31	20,05 / 19,72	16,44	16
	18 and 32	18,39 / 18,50	18,86	18
	19 and 34	17,37 / 17,60	21,69	20
	20 and 36	16,32 / 16,29	25,54	24
	21 and 38	15,30 / 15,50	27,89	26
	22 and 39	14,50 / 14,88	30,20	28
	23 and 40	14,00 / 14,19	34,06	30
	24 and 41	13,47 / 13,80	36,37	32

From this Table it appears that the resistances experienced by surfaces immersed to unequal depths in the fluid, do not follow the same law as the resistances to surfaces equally immersed. For these, the velocities being the same, the resistances increase in a greater proportion than the surfaces first plunged in the fluid; for the others, the contrary is the case. Hence we may conclude that, taking only the surfaces into consideration, every thing else remaining the same, bodies entirely immersed must experience rather less resistance than those which are only partly so.

As the same vessel was used in making all the experiments in the preceding Table, and that it was only the depths of the immersion which were varied, it would appear that, with the same velocity, the rising of the fluid should be constant; for the rising is produced by those parts which are near the surface: and experience proves that this is the case. There are, nevertheless, some few differences among the experiments, which must be accounted for by supposing them to be errors in the observations. It is therefore necessary to take a mean height for the risings, which is done in the following Table; the fourth column of which shows the resistances which are calculated, taking into account both the rising and the depression of the fluid, under the supposition that the depression is equal to two-thirds of the elevation; and from this it is estimated that the difference in the level from the fore to the after part is,—

In Experiments	17, 44, 31, . . .	26 lines.
—	18, 45, 32, . . .	30 —
—	19, 46, 34, . . .	34 —
—	20, 47, 36, . . .	38 —
—	21, 48, 38, . . .	43 —
—	22, 49, 39, . . .	48 —
—	23, 50, 40, . . .	53 —
—	24, 51, 41, . . .	58 —

Distinguishing Numbers of the Vessels Compared.	Experiments Compared.	Weight calculated, without taking the rising into consideration.	Weight calculated, taking the rising into consideration.	Weight shown by Experiment.
		Marcs.	Marcs.	Marcs.
No. 3. First and third Draught of Water.	17 and 44	21,15	18,84	20
	18 and 45	25,12	22,05	24
	19 and 46	29,96	25,95	28
	20 and 47	34,15	29,09	32
	21 and 48	39,47	33,21	36
	22 and 49	43,37	35,96	40
	23 and 50	46,64	38,15	44
	24 and 51	50,24	40,56	48
No. 3. First and second Draught of Water.	17 and 31	16,44	15,12	16
	18 and 32	18,86	17,17	18
	19 and 34	21,69	19,55	20
	20 and 36	25,54	22,81	24
	21 and 38	27,89	24,64	26
	22 and 39	30,20	26,41	28
	23 and 40	34,06	29,50	30
	24 and 41	36,37	31,22	32

From this Table it would appear, that the last column is a sort of mean between the preceding two, and that consequently the consideration of the alterations which take place in the level of the fluid, will again serve to reconcile the results of the experiments with those of the theory. The similarity between these two results would be increased, by taking a different proportion between the elevation of the water before the bow, and its depression at the stern. But it is unnecessary to dwell longer on these calculations, which are at the best extremely hypothetical; for it would be always very difficult, if not impossible, to determine exactly by observations the correct proportion for every case.

Section 3.—*In what Proportion do Oblique Resistances vary?*

Let ADB (Fig. 25) be an isosceles triangle moving in the direction QD in a fluid of infinite extent. AD will experience, according to the theory, a direct resistance FE, such that calling π the direct resistance experienced by the half-base

AQ, when moved with the same velocity as the triangle, the force FE =

$$\pi \times \frac{AD \times (sin\ ADQ)^2}{AQ \times (AD)^2} = \pi \times \frac{AD \times AQ^2}{AQ \times AD^2} =$$

$$\pi \times \frac{AQ}{AD};$$

and in a similar manner for the part BD, the force fe =

$$\pi \times \frac{BQ}{BD} = \pi \times \frac{AQ}{AD}$$

By resolving each of the forces FE, fe into two others FH, FK, fh, fk; the one perpendicular, and the other parallel to the base of the triangle, it is evident that the two equal and opposite forces FK, fk, destroy each other, and that the triangle is only acted upon in the direction QD, by one force $= FH + fh = 2\,FH = 2\ FE \times \frac{AQ}{AD} = 2\,\pi \times \frac{AQ^2}{AD^2}$

Hence if we call the force 2 FH $= p$, and P the whole force acting on the base AB when moved with the same velocity as the triangle, we have

$$p = P \times \frac{AQ^2}{AD^2}$$

To facilitate the more easy comparison of this formula with experiment, we will take from among the experiments which are comprised under the general title of Direct Resistances, and from among the Oblique Resistances, two vessels having the same breadth, and the same depth in the water. We will also determine the motive weights for the two vessels with the same velocity. One of these weights (take, for example, that which is relative to the direct resistance,) is immediately ascertained by experiment. The other, if it is not in the Table, may be calculated by the means of the experiments for the oblique resistances, and of the law that the resistances to the same vessel are in proportion to the squares of the velocities, when there is no great difference between the velocities.

We will take as an example the vessel No. 2, and compare it successively with each of the vessels Nos. 8, 9, 10, 11, and 12, which have equal breadth and draught of water with it.

First, according to experiment No. 10, the motive weight P being 24 marcs, the boat No. 2 uniformly describes twenty feet

in 17,32 half-seconds: we shall find from experiment No. 86, and from the law already named, that the motive weight p of the vessel No. 8, should be 20,18 marcs, that the vessel may describe twenty feet in 17,32 half-seconds. Now the theory from the formula $p = P \times \frac{AQ^2}{AD^2}$ gives $p = 19{,}20$ marcs.

In taking experiment 10 as a foundation, with relation to the vessel No. 2, and finding successively by means of the experiments Nos. 91, 97, 105, and 113, and of the law of the velocities, the motive weights of the vessels Nos. 9, 10, 11, and 12, so that these vessels shall have the same velocity as No. 2, we find

No. 9, $p =$	12,96 marcs nearly;	and by theory	$p =$	12, marcs.
No. 10, $p =$	10,80	—	— $p =$	7,38 —
No. 11, $p =$	8,39	—	— $p =$	4,80 —
No. 12, $p =$	8,32	—	— $p =$	3,31 —

We will now compare the two boats, Nos. 1 and 7, which have the same breadth aud depth in the water. According to he experiment No. 6, when the motive weight P is 22 marcs, the vessel No. 1 describes uniformly 20 feet in 12,75 half-seconds. And, by using the law of velocities, and experiment No. 75, that the motive weight p of the vessel No. 7 should be 8,68 marcs, nearly, to enable it to describe 20 feet uniformly in 12,75 half-seconds. The theoretic formula gives $p = 1{,}29$ marcs, nearly.

Without continuing these comparisons, we see that, with respect to the law of the square of the sign of the angle of incidence of the fluid on the plane, the results of theory differ more and more from those of experiment, in proportion as the angle in question diminishes. The motive weights, in oblique resistances, are always greater, according to experiment, than they should be, as deduced from the theory. When the angle of incidence is rather large, as, for example, for the vessels Nos. 8 and 9, where for the first it is 63° 28′, and for the second it is 45°, the results of the theory do not differ greatly from those of experiment. But for the vessel No. 10, where the angle of incidence is 33° 41′; for the vessel No. 11, where the

angle of incidence is 26° 34′; for No. 12, where it is 21° 49′; and for No. 7, where it is 14° 3′: the difference between the results of experiments and theory are considerable, and increase as the angle of incidence diminishes. It is not possible, therefore, to make use of theory to determine the resistances which are experienced in oblique shocks. In the same manner, theory is completely insufficient to determine the resistances experienced by curved surfaces, excepting in the case in which the surfaces do not meet the fluid under small angles of incidence.

Since we cannot maintain the law of the square of the sign of the angle of incidence, we must ascertain whether or not it is possible to substitute some other power of the sign which will account for the phenomena we have observed. We will suppose, then, that, instead of the equation, the force FE = $\pi \times \frac{AD \times (\sin ADQ)^2}{AQ\ (AD)^2}$, we have generally

$$\text{The force FE} = \pi \times \frac{AD \times (\sin ADQ)^n}{AQ \times (AD)^n}$$

$$= \pi \times \frac{AD \times AQ^n}{AQ \times AD^n} = \pi \times \frac{AQ^{n-1}}{AD^{n-1}}$$

$$\text{and consequently } p = P \times \frac{AQ^n}{AD^n}$$

which last equation gives

$$n = \frac{\log P - \log p}{\log AD - \log AQ}$$

Now from a mean result of five applications of this formula, for five experiments made with each of the six vessels, Nos. 8, 9, 10, 11, 12, 7, and compared with the experiments made with the vessels Nos. 2 and 1, we find,

For the vessel	No. 8 . . .	$n =$ 1,79
"	No. 9 . . .	$n =$ 1,59
"	No. 10 . . .	$n =$ 1,29
"	No. 11 . . .	$n =$ 1,08
"	No. 12 . . .	$n =$,92
"	No. 7 . . .	$n =$,66

This being established, all these values of n, which if the formula $p = P \times \frac{AQ^n}{AD^n}$ could account for the phenomena, should

be equal or nearly so; are, in fact, very different when the angles of incidence are different; we must conclude that we cannot explain by the theory the resistances arising from oblique shocks, by introducing any other power of the sign of the angle of incidence, in the expression for the resistance.

The general function of the time, space, surface, and sign of the angle of incidence, which shall represent the resistance in all cases, is worthy the consideration of mathematicians. We shall endeavour at some future opportunity to investigate it, at present we will continue our general comparison of the theory of resistances with experiment.

Section 4.—*To determine the absolute value of the Perpendicular and direct Resistance.*

The motion being considered uniform, the motive weight of each vessel is constantly in equilibrium with the resistance and friction of the water, and the resistance of the air to that part which is out of the water. The resistance of the air to the motive weight itself as it descends is not taken into consideration, as it must necessarily be very small on account of the smallness of the body. But the friction and the resistance of the air to the vessel should, of course, be taken into account, and deducted from the weight which experiment gives as the motive weight, in order that we may have the actual resistance experienced by the vessel: we will first consider the friction.

At the extremities of the rope which was used for the experiments, we fastened several pair of equal weights, and then suspended them over the upper pulley. The length of the rope was 152 feet, and its weight about 12 ounces. A small weight was then added to one side, just sufficient to destroy the equilibrium. This weight was taken to represent the friction, and was deducted from the moving weight; so that the remainder represented the true value of the resistance of the water and air.

The radius of the pulley added to the radius of the cord, was to the radius of the pin nearly in the proportion of 31 to 2.

Hence it will be seen, from the following Table, that the friction is about equal to one-fifth of the pressure. This result of the friction is for a state of equilibrium; when the machine is in motion, the friction may be estimated as being rather less.

Table to ascertain the Friction.

Sum total of the two weights suspended.	Sum total of the weights, including that of the cord.		Weights added, in order to overcome the friction.	
Marcs.	Marcs.	Ounces.	Ounces.	Grains.
16	17	4	1	5
20	21	4	2	0
24	25	4	2	4
28	29	4	3	0
32	33	4	3	3
36	37	4	3	7
40	41	4	4	3
44	45	4	4	6
48	49	4	5	2
52	53	4	5	5
56	57	4	6	0
60	61	4	6	3
64	65	4	6	6
68	69	4	7	2
72	73	4	7	6
76	77	4	8	2
80	81	4	8	6
84	85	4	9	2
88	89	4	9	6
92	93	4	10	1
96	97	4	10	4
100	101	4	11	0

In this Table we have only taken into consideration the friction arising from the upper pulley; but we also ought to take into consideration that of the lower one, which will be

less than the other, as here the two ropes form a right angle with each other. Under all circumstances, we conclude that, if there were no friction, the motive weights of the experiments should be reduced to the following :—

For 6 marcs,	or 48 ounces,	say $46\frac{1}{2}$ marcs.
8	64	62
10	80	$77\frac{1}{2}$
12	96	93
14	112	$108\frac{1}{2}$
16	128	124
18	144	$139\frac{1}{2}$
20	160	155
22	176	$170\frac{1}{2}$
24	192	186
26	208	$201\frac{1}{2}$
28	224	217
30	240	$232\frac{1}{2}$
32	256	248
34	272	$263\frac{1}{2}$
36	288	279
38	304	$294\frac{1}{2}$
40	320	310
42	336	$325\frac{1}{2}$
44	352	341
46	368	$356\frac{1}{2}$
48	384	372
50	400	$387\frac{1}{2}$

Having thus nearly ascertained the effects of the friction, we can also very nearly determine the value of the resistance of the air for each vessel, by measuring the area of the surface exposed to the action of the air, and by following the principle that, with the same velocities, the action of both air and water against different planes is in a ratio compounded of the surfaces and the densities of the fluids. We will apply this to several examples taken from among the experiments on direct and perpendicular resistances. Now, to apply this to experiments Nos. 1, 12, 20, 34, 48, (Chap. 2d), and No. 6, (Chap. 4th). The motion will be considered as that for the last 20

feet of the space described. We will suppose for each vessel, Q equal to the motive weight minus the quantity due to the friction, and R and r the resistances of the water and air.

Then, for experiment No. 1 with the vessel No. 1, the two planes opposed to the water and the air are to each other as 12 inches to 6, or as 2 to 1: consequently, under the supposition that the densities of these fluids are to each other as 850 to 1, we have $R : r :: 2 \times 850 : 1 :: 1700 : 1$. Now, $R + r = Q$; therefore $r = Q \times \frac{1}{1701}$, and $R = Q \times \frac{1700}{1701}$.

For experiment No. 12, with the vessel No. 2, the two planes opposed to the water and the air are to each other as $2 : 1$. Therefore $r = Q \times \frac{1}{1701}$, and $R = Q \times \frac{1700}{1701}$.

For experiment No. 20, with the vessel No. 3, to its first draught of water, the planes opposed to the water and the air are to each other as 7 inches 10 lines to 11 inches 10 lines, or as 47 to 71. Therefore $R : r :: 850 \times 47 : 71 :: 39950 : 71$. Therefore $r = Q \times \frac{71}{40021}$, and $R = Q \times \frac{39950}{40021}$.

For experiment No. 34, with the vessel No. 3, to its second draught of water, the two planes opposed to the water and the air are to each other as 299 to 173: therefore, $R : r :: 850 \times 299 : 173 :: 254150 : 173$. Consequently, $r = Q \times \frac{173}{254323}$, and $R = Q \times \frac{254150}{254323}$.

For experiment No. 48, with the vessel No. 3, to the third draught of water, the two planes are to each other as 95 to 23. Therefore $R : r :: 850 \times 95 : 23 :: 80750 : 23$. Consequently $r = Q \times \frac{23}{80773}$, and $R = Q \times \frac{80750}{80773}$.

Lastly, for experiment No. 6 (Chap. 4th), with the vessel No. 21, the two planes opposed to the water and air are to each other as 299 to 173. Therefore, $R : r :: 850 \times 299 : 1 \times 173 :: 254150 : 173$. Therefore, we have $r = Q \times \frac{173}{254323}$, and $R = Q \times \frac{254150}{254323}$.

It is evident that, in all cases, we shall have the values of r and R, by substituting for Q its value determined in the above manner. These calculations show that the resistance of the air is extremely small, when compared to that of the water.

We shall, therefore, content ourselves with noticing the values of R.

		Ounces.		Ounces.
If (Experiment 1)	Q =	93,	we have R =	92,94
If (Experiment 12)	Q =	248,	R =	247,85
If (Experiment 20)	Q =	124,	R =	123,78
If (Experiment 34)	Q =	155,	R =	154,90
If (Experiment 48)	Q =	279,	R =	278,92
If (Experiment 6)	Q =	465,	R =	464,69

We will now consider the value of R, with relation to the surface of the vessel opposed to the impulse of the water, and to the velocity due to that impulse.

A cubic foot of water weighs 70 pounds nearly. Suppose M the mass of a cubic foot of this water; N the mass of a quantity of water equal in weight to R, expressed in pounds; s^2 the surface opposed to the fluid; and h a height, such that hs^2 shall equal N; h' the height due to the velocity with which the vessel moves. Then, $N = M \times \frac{R}{70}$; and, consequently, $hs^2 = M \times \frac{R}{70}$, or $h = \frac{M}{s^2} \times \frac{R}{70}$. To find the value of h', to compare it with that of h, we will express the two values in inches. By making these calculations for the experiments in the preceding article, we shall find

			Inches.		Inches.
Experiment	1	- h =	0,99	- h' =	1,08
—	12	- h =	1,32	- h' =	1,39
—	20	- h =	1,28	- h' =	1,19
—	34	- h =	1,01	- h' =	1,03
—	48	- h =	1,43	- h' =	1,47
—	6	- h =	1,44	- h' =	,84

From this it is seen, that the values of h and h' never differ much from each other. The differences may be attributed either to errors in the observations, or in the estimation of the values of the resistance of the air, and the friction. Consequently, may be supposed, without fear of any sensible error, that, in practice, *the perpendicular and direct resistance to a plane surface, moving in an infinite fluid, in a direction parallel to itself, is equal to the weight of a column of the same fluid, the base of which is equal to the surface opposed to the fluid; and*

the height equal to that which is due to the velocity with which the impulse of the plane against the fluid is given.

The resistance of fluids in narrow channels is much greater than that of fluids which are infinite in extent, as we shall see as we proceed.

It now only remains to make a few observations on the tenacity of fluids, and on the friction which a vessel experiences in the direction of its length.

We endeavoured to estimate the tenacity of water, by measuring, with a weight, the force required to put a body in motion from a state of rest, when floating on the fluid; and we remarked that, the instant the friction was overcome, a very small force would suffice to put the vessel in motion. From this it may be concluded that the tenacity of the water is very small, and that this resistance may be considered as vanishing in comparison to that which arises from the inertia.

The same may be said of the friction of the water along the sides and the bottom of the vessel. This friction is so small, that, unless the vessel were of a very great length, it would be impossible to separate it from that of the pulleys and the resistance of the air. The truth of this may be established by reference to experiments Nos. 52, 53, 54, 55, and 31, 34, 36, and 39.

We also see, from the comparison we have made, that the vessel used in the experiments 52, 53, 54, and 55, experiences rather more resistance than that used in experiments 31, 34, 36, and 39; although the former vessel is shorter than the latter, the other dimensions being similar in both. This is contrary to what we should be led to expect from the friction of the water: the reason is, that when a body moves in a fluid, it should have sufficient length to enable the hollow which it forms behind it to be easily filled by the water which is at the sides, and that, by this motion in the fluid, the difference from the level at the forward and after parts of the body will be diminished.

General Conclusions from this Chapter.

It follows, then, from what has been said throughout the foregoing Chapter,

First,—That the resistances experienced by the same body, whatever may be its figure, moved with different velocities through a fluid infinite in extent, are very nearly in proportion to the squares of the velocities. It has been shown, that the resistances increase in a rather greater ratio than that of the squares of the velocities. Experiment, therefore, agrees on this point very nearly with theory.

Secondly,—That the perpendicular and direct resistances of several plane surfaces, moved with the same velocity, are very nearly proportional to the areas of the surfaces. This proportion may be brought very near to equality, by considering the different effect produced by the different vessels in the rising and depression of the fluid. Consequently, experiment and theory may be said to agree also on this point.

Thirdly,—That the resistances which arise from motion in oblique directions, do not diminish, every thing else remaining the same, in proportion to the squares of the sines of the angles of incidence; therefore, on this third head, the common theory of the resistance of fluids should be abandoned altogether, when the angles of incidence are small, as then the results deduced from it would be very erroneous. It is evident, also, that it cannot be employed to find the solid of least resistance, nor generally to determine any curve; for, in such problems, the law of the curvature is an unknown element. But for cases in which the angles of incidence are large, as from 50 to 90 degrees, we may make use of the theory; always remembering, that the resistances which will result will be rather less than those given by experiment, and that the error will be greater in proportion as the angles of incidence are smaller.

Fourthly,—That the perpendicular and direct resistance of a plane in a fluid of infinite extent is nearly equal to the weight of a column of the fluid, of which the base is equal to the surface of the plane, and the height equal to that which is due to the velocity with which the impulse is given.

Fifthly,—That the tenacity of the water may be considered as vanishing, when compared with the resistance arising from the inertia. The same observation applies to the friction, which cannot be of any importance, excepting in a case in which a vessel has a most excessive length in comparison to her breadth.

Chap. 6.—*A Comparison of the Resistances of Fluids in Narrow Channels, with those of Fluids infinite in extent.*

A body at rest, floating on a fluid, is supported in a vertical direction by the same force, whatever may be the dimensions of the fluid. From this principle, it may appear indifferent, with regard to the resistance, whether a vessel moves in a fluid of less or more extent. It is evident that the difference cannot be very considerable when the velocity is small. But it is also evident, that when a vessel moves with any considerable velocity in a narrow channel, the fluid which is forced up before it, not having a free passage to disperse itself at the sides, nor under the bottom if the channel is at the same time shallow, must oppose a greater degree of resistance to the vessel than would be the case were it not confined by the sides and bottom of the channel. Experiment will decide on the correctness of this reasoning.

Previous to giving (Chap. 3) the experiments on the resistances of fluids in narrow channels, the method in which they were conducted was described. It is necessary here to add, that the vertical sides of the channel did not extend to the extremity of the basin, but that there was a space of three feet left, for a communication between the water in the channel and that in the basin. The channel being then open at each end, the fluid which is forced before the vessel in its passages can escape by the one aperture, while the fluid in the basin can enter by the other and fill up the space left behind the vessel; consequently this case is precisely similar to that of a vessel moving in a narrow channel of infinite length. After a full examination of this case, we have also determined the resistance under the supposition that the channel is shut at each end.

By comparing the resistances experienced by the same vessel moved with different velocities, in channels of different breadths and depths, with each other; it was found that for each channel the resistances were nearly in proportion to the squares of the velocities, as in fluids of infinite extent. This will be seen in the following Table, the fourth column of which contains the weights calculated from a weight given by experiment, and after

the hypothesis, that the resistances are in each case proportional to the squares of the velocity.

The experiments 73, 74, 75, are not included in this Table, because they very nearly resemble others which are contained in it, and that they only serve to elucidate the remark which immediately precedes them. The three experiments alluded to were made in a channel which was open at each end.

Relation between the Resistances, according to Theory and according to Experiment, experienced by the same Surface when moved with different Velocities in a narrow Channel which is open at each end.

Depth and Breadth of the Channel.	Distinguishing Number of the Vessel.	Number of the Experiment	Time occupied in describing the last 20 feet.	Weight calculated by Theory.	Weight shown by the Experiment.
			Half Seconds.	Marcs.	Marcs.
First Depth and Breadth.	1	1	19,04	16..base	16
		2	17,25	19,49	20
		3	15,95	22,80	24
		4	14,60	27,21	28
		5	14,40	27,98	32
"	2	6	23,25	32..base	32
		7	21,25	38,31	40
		8	19,92	43,60	48
		9	18,50	50,54	56
"	4	10	23,90	24..base	24
		11	21,20	30,50	32
		12	19,15	37,38	40
		13	17,50	44,76	48
"	5	14	23,85	24..base	24
		15	21,15	30,52	32
		16	18,66	39,21	40
		17	17,15	46,41	48
"	6	18	21,35	24..base	24
		19	18,80	30,95	32
		20	16,90	38,30	40
		21	15,56	45,18	48

Depth and Breadth of the Channel.	Distinguishing Number of the Vessel.	Number of the Experiment	Time occupied in describing the last 20 Feet.	Weight calculated by Theory.	Weight shown by the Experiment.
			Half Seconds.	Marcs.	Marcs.
First Depth and Second Breadth.	1	22	17,20	16..base	16
		23	15,75	19,08	20
		24	14,40	22,82	24
		25	13,10	27,58	32
"	2	26	21,80	32..base	32
		27	19,70	39,19	40
		28	18,10	46,42	48
"	5	29	22,62	24..base	24
		30	19,85	31,16	32
		31	17,80	38,76	40
		32	16,30	46,22	48
"	6	33	19,81	24..base	24
		34	17,24	31,69	32
		35	15,85	37,49	40
Second Depth and Third Breadth.	1	36	15,25	16..base	16
		37	13,75	19,68	20
		38	13,00	22,01	24
"	2	39	18,00	32..base	32
		40	16,60	37,62	40
		41	15,30	44,29	48
"	5	42	20,07	24..base	24
		43	17,50	31,57	32
		44	16,00	37,76	40
		45	15,00	42,97	48
"	6	46	17,70	24..base	24
		47	15,50	31,29	32
		48	13,90	38,92	40
Third Depth and Fourth Breadth.	2	49	16,41	32..base	32
		50	14,80	39,34	40
		51	13,75	45,58	48

Depth and Breadth of the Channel.	Distinguishing Number of the Vessel.	Number of the Experiment.	Time occupied in describing the last 20 Feet.	Weight calculated by Theory.	Weight shown by the Experiment.
			Half Seconds.	Marcs.	Marcs.
Third Depth and Fourth Breadth.	5	52 53 54	15,94 14,50 13,38	32..base 38,67 45,42	32 40 48
Fourth Depth and Breadth infinite.	2	55 56 57	16,00 14,50 13,50	32..base 38,96 44,95	32 40 48
"	5	58 59 60	15,13 13,60 12,58	32..base 39,60 46,29	32 40 48
Second Depth and First Breadth.	7	61 62 63	16,40 15,25 14,45	16..base 18,50 20,61	16 20 24
"	9	64 65 66	22,96 21,13 19,10	32..base 37,78 46,24	32 40 48
	The Channel being closed at each End.				
Second Depth and First Breadth.	1	67 68 69	19,00 17,25 16,13	16..base 19,41 22,20	16 20 24
"	2	70 71 72	26,40 24,40 22,95	32..base 37,46 42,34	32 40 48

This Table, when compared with the first in chapter the fifth, affords an easy method of finding the proportion between the resistance in a narrow channel, and that in a fluid of infinite extent. For we have only to take the same vessel which was used in either case, and find, from the law that the resistances are as the squares of the velocities, the motive weight necessary to impel the vessel in a narrow channel with the same velocity with which it moves in a fluid of infinite extent, when impelled by the force of a known weight: then these two weights will be to each other very nearly in proportion to the required resistances. We will apply this method to several examples separately, as each will furnish us with some observation. Suppose F to represent the resistance in the narrow channel, f the resistance in relation to an equal velocity in a fluid of infinite extent. The distinctions made in the channels are in consequence of the difference of their transverse sections, the length being constant.

Direct Resistances, the Channel being open at each End.

First channel, with the vessel No. 1. According to the first experiment (Chapter 5th., Table 1st.) the moving weight being 12 marcs, the vessel described 20 feet in 17,08 half seconds, or 40 feet in 17,08 seconds in a fluid of infinite extent; and, according to the preceding Table, the moving weight being 20 marcs (Experiment 2nd) it describes 20 feet in 17,25 half seconds, or 40 feet in 17,25 seconds in a narrow channel. Consequently, that it may describe 20 feet in 17,08 half seconds, a motive weight of 20,40 marcs must be employed. Therefore $F : f :: 20{,}40 : 12$. The last proportion is rather too large, in consequence of a slight difference in the frictions. But we may strictly say $F : f :: 5 : 3$, from which we see that the vessel experiences much more resistance in the narrow channel than in the infinite fluid.

In the channel the depth of water beneath the vessel is 3 inches 2 lines; and the distance between each of the sides of the vessel and the sides of the channel is 8¼ inches. It is in consequence of this want of space for the escape of the water that F so much exceeds f.

Let the vessel be No. 2. The 8th Experiment (Chapter 5th) shows that when the motive weight is 16 marcs, the vessel describes 40 feet in 21″, 11; and from Experiment No. 7 of the preceding Table it will be found that it requires a motive weight of 40,54 marcs to produce the same velocity in a narrow channel. Therefore F : f :: 40,54 : 16 or nearly as 5 : 2.

In the narrow channel, the depth of water below the vessel is 3 inches 2 lines, and the distance between the sides of the vessel and the sides of the channel is 2¼ inches; from which it is evident that the difference between F and f must be greater in this than in the preceding case.

Let the vessel be No. 4. In Experiment 52 (Chapter 5th) when the moving weight is 16 marcs, the velocity is 40 feet in 19″, 85; and from Experiment 11 of the preceding Table, it requires a moving weight of 36,50 marcs to produce the same velocity in a narrow channel. Therefore F : f :: 36,50 : 16 or as 9 : 4 nearly.

The depth of water in the channel beneath the vessel is 2 inches 8½ lines, and the space at each side is 4 inches 5 lines. We see that the diminution of the depth of water beneath the vessel very greatly increases the relation of F to f.

Let the vessel be No. 6. In Experiment 60 (Chapter 5th) when the moving weight is 16 marcs, the velocity is 40 feet in 18″, 83; and from Experiment 19 of the preceding Table, it requires a moving weight of 31,90 marcs to produce the same velocity in a narrow channel. Therefore F : f :: 31,90 : 16 so is 33 to 17 nearly.

The water beneath the vessel is 2½ inches, and on each side the space is 4 inches 5 lines. The water in this case has rather less difficulty in escaping than in the former one; and consequently the relation of F to f is rather less.

Second channel.—With the vessel No. 1. In Experiment 1, (Chapter 5th) when the moving weight is 12 marcs, the velocity is 40 feet in 17″, 08 and from Experiment 22 of the preceding Table, it requires a moving weight of 16,22 marcs in the narrow channel to produce the same velocity. Therefore F : f :: 16,22 : 12 so is 4 to 3 nearly.

The depth of water beneath the vessel is 3 inches 2 lines; and the space on each side is 14 inches. In comparing this

case with the first of the preceding article, it appears that the increase of breadth to the channel, the depth remaining constant, has greatly diminished the resistance.

With the vessel No. 2. In Experiment 8 (Chapter 5th) when the moving weight is 16 marcs, the velocity is 40 feet in 21″, 11; and from Experiment 26 of the preceding Table, it requires a moving weight of 34,12 marcs to produce the same velocity in the narrow channel. Therefore F : f :: 34,12 : 16 or as 19 : 9 nearly.

The depth of water beneath the vessel is 3 inches 2 lines; and the space on each side is 8 inches. By comparing this with the second of the foregoing cases, it will be seen that the resistance diminishes in proportion as the channel is increased in size.

With the vessel No. 6. In Experiment 60 (Chapter 5th) when the moving weight is 16 marcs, the velocity is 40 feet in 18″, 83; and from Experiment 33 of the preceding Table, it requires a moving weight of 26,56 marcs to produce the same velocity. Therefore F : f .: 26,56 : 16 so is 13 to 8 nearly.

The depth of water beneath the vessel is $2\frac{1}{2}$ inches; and the space at each side is 10 inches 2 lines. Compare this case with the fourth of the preceding cases.

Third channel.—With the vessel No. 1. In Experiment 2 (Chapter 5th) when the moving weight is 14 marcs, the velocity is 40 feet in 15″, 90; and from Experiment 36 of the preceding Table, it requires a moving weight of 14,72 marcs to produce the same velocity in the narrow channel. Therefore F : f :: 14,72 : 14 or nearly as 19 to 18.

The depth of water beneath the vessel is $3\frac{1}{2}$ inches; and the space at each side is $31\frac{1}{2}$ inches. These spaces may be considered as infinite. We see that F very nearly approaches to f, but that still F is greater than f, as the fluid is confined at the bottom.

With the vessel No. 2. In Experiment 10 (Chapter 5th) when the moving weight is 24 marcs, the velocity is 40 feet in 17″,32; and from Experiment 39 of the preceding Table, it requires a moving weight of 34,56 marcs to produce the same velocity in the narrow channel. Therefore F : f :: 34,56 : 24 or nearly as 18 : 13.

The depth of water beneath the vessel is $3\frac{1}{2}$ inches; and the space on each side is $25\frac{1}{2}$ inches. Here the water meets with obstruction not only beneath, but at the sides of the vessel.

Fourth channel.—With the vessel No. 2. In Experiment 11 (Chapter 5th) when the moving weight is 28 marcs, the velocity is 40 feet in 16″,12; and from Experiment 49 of the preceding Table, it requires a moving weight of 33,16 marcs to produce the same velocity in the narrow channel. Therefore $F : f :: 33{,}16 : 28$, or nearly as 9 to 8.

The breadth of the channel is infinite, but the depth of water beneath the vessel being only $3\frac{1}{2}$ inches causes the excess of F above *f*.

Fifth channel.—With the vessel No. 2. In Experiment 11 (Chapter 5th) when the moving weight is 28 marcs, the velocity is 40 feet in 16″,12; and from Experiment 55 of the preceding Table, we find that it requires a moving weight of 31,52 marcs to produce the same velocity in the narrow channel. Therefore $F : f :: 31{,}52 : 28$, or nearly as 11 to 10.

The breadth of the channel is infinite, and the depth beneath the vessel is $15\frac{1}{4}$ inches. It appears that even this depth does not allow of free passage to the fluid, or it may be, perhaps, that the difference between F and *f* may arise from error in the observations.

Oblique Resistances, the Channel being open at each End.

Sixth channel.—With the vessel No. 7. In Experiment 75 (Chapter 5th) we find that when the moving weight is 10 marcs, the velocity is 40 feet in 11″,88; and from Experiment 61 of the preceding Table, it requires a motive weight of 30,49 marcs to produce the same velocity in a narrow channel. Therefore $F : f :: 30{,}49 : 10$, or as $34 : 11$ nearly.

The depth of water beneath the vessel is $3\frac{1}{2}$ inches, and the space at each side is $8\frac{1}{4}$ inches. By comparing this case with the first in the first channel, it will be seen that, every thing else remaining the same, a sharp angular bow has much less effect in diminishing the resistance in a narrow channel than in a fluid of infinite extent.

The reason is obvious. In the narrow channel the water

when parted by the sharp bow is retained by the sides of the channel, and re-acts against the bow; while, in the fluid of infinite extent, the water divided by the bow disperses itself. This observation will be proved by the next example.

With the vessel No. 9. In Experiment 91, (Chapter 5th) it requires a moving weight of 12 marcs to produce a velocity of 40 feet in 18″ in the infinite fluid; and from Experiment 64 of the preceding Table, a weight of 52,06 marcs is necessary to produce the same velocity in a narrow channel. Therefore $F : f :: 52,06 : 12$, so is $51 : 12$, nearly.

Direct Resistance, the Channel being closed at each End.

Channel the sixth.—With the vessels 1 and 2. If by means of the preceding Table, each is compared with each. First, the Experiments 67, 68, 69, with Experiments 1, 2, 3, and then Experiments 70, 71, 72, with 6, 7, and 8; it will be seen that for the vessel No. 1, the resistance is nearly the same, when the channel is shut, as when it is open: but for the vessel No. 2, it is evidently greater when the channel is shut, than when it is open. In fact, the fluid which is driven before each vessel and intercepted by the foremost end of the channel, has much more room to return by the sides of No. 1, than of No. 2, which is much larger.

The two channels compared are of the same breadth, but this which is now referred to is 4 lines deeper than the former, which of course would rather tend to diminish the resistance.

General Conclusions from this Chapter.

It results from the experiments and calculations which have been gone through, that the resistance of fluids contained in narrow, or shallow channels, is greater than that of fluids which are of infinite extent. The difference may be very great; it depends on the transverse dimensions of the channel, and on the form of the vessels which are compared.

It has been observed that in a narrow channel the fluid which is displaced by the vessel's motion, or at least a part of it, is forced before the vessel and forms a current more or less rapid in proportion to the rapidity of the motion of the vessel.

This current must exist with greater or less rapidity in every confined channel. For if the vessel exactly filled the transverse section of the channel, the whole of the water would be forced forwards ; but as there is always some space left, a part of the fluid will escape by that space, and only the remainder will be forced forward : which produces a contrariety of currents. The less facility the water has afforded it to pass from the fore to the after part of the vessel, the greater the current is in a contrary direction, and consequently the less is the vessel supported towards its after parts ; from which there results an augmentation of resistance.

We see from this how necessary it is to give the greatest possible breadth and depth to canals, and consequently tunnels for canals should always be avoided if possible, as the cost of forming them is so great that it will not admit of their being of sufficient dimensions for the purposes of navigation; and therefore the time employed in the passage through a subterranean canal is far greater than in an open one.

Art. XL.—*Remarks on the Circular Sterns introduced into His Majesty's Navy by Sir Robert Seppings, Surveyor of the Navy, F.R.S., &c.*[1]

The consideration of the comparative advantages of square and circular sterns, is especially a subject of common sense and experience. The excellencies attributed respectively to each of these forms, admit of being easily understood and fully examined; and the objections brought against them admit of being fairly investigated. Although the opinions of experienced naval officers are particularly important on this subject,—on which, indeed, the general approval of the introduction must finally rest,—yet, as the arguments are such, as do not depend

[1] Much of the matter in this paper is taken from Sir Robert Seppings's Letter addressed to Lord Viscount Melville, on the introduction of circular sterns, and from a paper on this subject by Mr. Harvey, in the Journal of Science and the Arts, No. 36.

on any professional technicalities or difficulties in naval tactics or seamanship, they are capable of being generally understood by all interested in the subject.

As the construction of vessels was directed in early periods by the simplest principles, such forms were adopted as appeared most obviously to answer the intended object. Experience, no doubt, soon taught the builders, that a body moving in water with its extremities terminated by plane surfaces perpendicular to the direction of its motion, meets with a much greater resistance than if the extremities of the body were formed by surfaces inclined to the direction of its motion; and as rudders were an early invention, that their effect in turning a vessel was greater, when the after-part tapered, so as to allow the water to flow more directly on them, than when the after-part was terminated by a plane surface perpendicular to its length; so that the earliest vessels must have been formed with their extremities, below the water's surface, tapering forward and aft, as our present ships. The same form, with perhaps increased fulness, was continued above the water both forward and abaft, till circumstances directed an alteration; so that it is not improbable, that the earliest vessels had their sterns of a curvilinear form as well as their prows.

From the nature of the warfare of the ancient galleys, in which the prows were armed for attack, and their after-parts chiefly appropriated to the accommodation of the officers, *not being in any way connected with the military fittings*, it was thought proper to gain as much room abaft as possible, which was obviously obtained by continuing the breadth of the vessels aft, and terminating their extremities by square sterns. Quarter galleries were afterwards added, outside the vessels. As the size of the galleys was increased, the sterns were formed of several tiers of cabins, with large quarter-galleries, rendering the sterns excessively weighty and unshapely; which the constructors endeavoured to render pleasing to the eye by a profusion of carved and other ornamental work.

As the practical construction of vessels gradually improved, the enormous height of the sterns was reduced, in order to render the weight of the after-part of the ship less excessive, when compared with the support of the water acting on the corre-

sponding part of the body below the water's surface. The strain of the great weight of the sterns of ships, occasioned by the inadequate support given by the vertical pressure of the water on the fine after-part of the body, is necessarily very great, and causes a constant tendency to break the sheer abaft; which is the less, the more the weight of the stern is reduced. On this account it is desirable, that the sterns of ships should be rendered as light as possible;—although the circumstances of the case must always prevent the downward pressure of the weight and the upward pressure of the water being equal, yet the reduction of the excess of the weight should be always kept in view in the construction of the sterns of ships.

When cannon were generally introduced on board ships, their additional weight rendered it the more necessary to reduce the weight of the fabric at the after extremity, and to increase the strength. The improvements of the sterns of ships may be traced more particularly from that period; although their progress was exceedingly slow. Had cannon been used on board ships when they were first constructed, it is most probable that square sterns would never have been given to ships of war.

There are in the nature of square sterns two most important defects, which may be shown by general reasoning, and may be more satisfactorily proved by the evidence derived from the experience of many naval officers: the one, a weakness in the sterns, occasioned by the disposition of the materials in a form mechanically wrong in its principle; and the other, a military weakness in the sterns of ships of war, both as to attack and defence, occasioned by the *form* of the stern, which causes a bad disposition of the guns, particularly in the want of guns on the quarters.

The first of these defects may be best seen from a consideration of the disposition of the materials composing a square stern.

The lower part of the square stern was formed of horizontal transverse timbers, of great dimensions, called transoms, which extended upwards to a little above the gun-deck, strengthened internally by large timbers, lying nearly in a fore and aft direction, called sleepers; and the upper part of the stern was

formed of timbers placed to the rake of the stern, their heels tenoning into the wing-transom, and having iron plates bolted to their heels and to the wing-transom, and secured above, by deck and seat-transoms, with wooden or iron knees, connecting the stern with the ship's sides.

The defects of this combination of materials were: the great difficulty of procuring, and the great expense of, the transoms; the great weakness of the connexion of the heels of the midship counter-timbers with the wing-transom, all abutting at the same height, and quite inadequate to sustain the strain of the upper part of the stern, which, by the rake aft, constantly tended to trip their heels; and the connexion of the ship's sides with the sterns, formed by the wooden or iron knees, which, from being necessarily unsupported by any brace, were mechanically a weak mode of fastening. The great strain brought by the weight of these sterns on the fastenings, which connect the sides of the ship and the stern, gradually weakened them, allowed them to work, and caused the seams to leak, by which the timber of which they were composed was decayed, and the accommodation of the cabins injured by the admission of the water. In the case of square-sterned ships being pooped, the sea frequently broke into the after-cabins, which had but few timbers to protect them, carrying in all the sashes and small fittings of the stern, and sometimes the great body of water which was admitted carried away the bulkheads of the cabins.

The weakness of the square sterns is further shown by the evidence of naval officers, some of whose reports are here given, taken from a table of numerous reports of the defects of ships with square sterns, given in the Appendix to Sir Robert Seppings's Letter to the Right Hon. Lord Viscount Melville.

SHIPS OF THE LINE.

Rate.	Guns.	Ships' Names.	Captains' Names.	Date.	NATURE OF DEFECTS.
3	74	Courageux..	Bertie........	Feb. 1804.	"In a violent heavy gale of wind, between the 17th and 28th January, carried away five tillers, owing principally to the working of the stern-frame and rudder-head. On the 26th, 27th, and 28th, the gale being so heavy, and a tremendous sea running, the tiller gave way again; and the working of the ship abaft, about the stern-frame and post, was so much, *as to think it advisable to throw* 12 *guns overboard from abaft, to ease and lighten her*."
2	98	Dreadnought	Purvis........	Mar. 1804.	"The heels of the two midship stern timbers are tripped from their steps on the wing-transom, and, from the working of the stern, the lead in the upper part is so much broke, as to require shifting."
3	80	Canopus....	Austin........	April 1806.	"The stern-frame is very weak."
3	64	Monmouth..	King	Aug. 1808.	"The stern-frame appears loose and requires strengthening."
3	84	Christian VII.	Yorke	June 1809.	"The lower counter appears to work very much at the stern-post."
3	84	Ganges	Dundas	Mar. 1811.	"The stern-frame and post work so much that the oakum works out, and the nails are drawn in the end of the deck, which occasion leaks in the bread-room."
3	74	Hannibal ..	Seymour.......	Nov. 1812.	"A great deal of lead of the round-house, quarters, and stern, is rubbed off and broke by the working of the stern."
3	74	Victorious ..	Talbot........	Aug. 1814.	"The counter and buttocks worked and strained much in the last winter's gale."
3	74	Vengeur....	Rickets	April 1815.	"The upper part of the stern and poop proves to be very weak."

FRIGATES.

Rate.	Guns.	Ships' Names.	Captains' Names.	Date.	NATURE OF DEFECTS.
5	32	Aquilon	Cracraft	May 1796.	"The stern-frame much shook by firing the after-guns."
4	50	Adamant ..	Hotham	Dec. 1801.	"The stern-frame has fallen, so that the stern-timbers are nearly out of their steps on the wing-transom."
5	36	Penelope....	Broughton	Nov. 1804.	"The stern in general works much at sea."
5	32	Pallas......	G. F. Seymour	Feb. 1809.	"The counter is very leaky, occasioned by the working of the stern and counter timbers."
4	50	Leopard	Dillon........	Nov. 1813.	"She complains much in her stern-frame."
5	36	Nymphe....	Pigot	June 1815.	"All the stern-frame very loose, and works much."

These few examples present a fair character of the weakness of the square sterns of *modern* ships: the square sterns of *old* ships were generally much weaker. In the tables from which the preceding examples are taken, the reports on the *same* ships under the command of different captains are given, showing the agreément of their opinions on the weakness of the square sterns.

Fully convinced of the weakness of the square sterns, it became necessary to consider the best means of removing this very serious defect. The stern-walks were given up in the two-decked ships, to reduce the weight of the sterns, and thereby diminish their weakness. Additional fastenings were introduced: iron truss-work, knees, and straps were fitted on the inside of the stern-frame, which connected the stern-timbers more securely to each other and to the ship's sides, and their heels to the wing-transom. The transoms below the wing-transom were substituted by vertical timbers. By these means the difficulty of procuring timber of large dimensions and great curvature was reduced, and the stern generally strengthened. Still, however, the cause of the weakness, the bad mechanical disposition of the materials, was not removed, though by additional fastenings its effect was diminished. The obvious improvement then presented itself, the better arrangement of the materials; and the circular form was consequently adopted, which gave adequate and uniform strength to the stern; as well as being at the same time best adapted to answer the end of increasing the military force of the ship in attack and defence,—which will be considered separately. In the circular stern the timbers of the frame are continued all round to the stern-post, and the exterior and interior planking is carried round, and the stern strengthened internally by the water-ways, and deck-hooks connected with the shelf-pieces; the diagonal framing extending up to the gun-deck is also continued to the stern: the whole stern being thereby rendered equally strong all round, and possessing strength equal to the bows. Fig. 26 shows the disposition of the timbers of the old square sterns; Fig. 27, the disposition of the timbers in the improved square sterns, with the vertical timbers substituted for the transoms below the wing-tran-

som; and Fig. 28, the disposition of the timbers in the circular sterns.

The reports of naval officers on the strength of the circular sterns fully justify the conclusion, to which a consideration of their construction leads.

The next consideration, with respect to the substitution of circular for square sterns in ships of war, is the defect of the square sterns as to the disposition of the cannon both for attack and defence, and the proper adaptation of the form of the circular sterns to remedy this very important defect.

It is, however, not uncommon, though much less frequent now than at the first introduction of circular sterns, to hear it said, that increasing the defence of the sterns of British ships of war is altogether unnecessary,[1] as no case is supposed probable, if possible, to occur, in which they will run from an enemy. Without for a moment admitting that a British ship ever refuses an engagement with an enemy, even of considerable superiority of force, yet it must be allowed, that there have been and must be instances, in which inevitable capture must be the consequence of engaging an overwhelming force of an enemy. But there are also circumstances wholly independent of retreat, in which the additional force in the circular sterns may be found necessary. When a ship is aground, the most serious injury may arise from an attack of an enemy on the quarters: gun-boats have been found particularly annoying under such circumstances. A ship in a calm, or at anchor under an enemy's fort, or dismasted in an engagement, is liable to the most dangerous consequences, by the want of quarter guns. Ships convoying merchant ships, by the use of stern and quarter guns, may continue an unequal engagement, so as to allow the convoy to escape. It is said, that when such extreme instances occur, the quarter galleries may be shot away: this, indeed, has been done; but not without danger from the in-board explosion, expensive injury to the ship, and, after all, obtaining only a very inferior substitute for the quarter-ports of the circular sterns.

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[1] It may be remarked, that this objection implies the admission of the superiority of defence in the circular sterns.

The want of guns on the quarters of square-sterned ships was not their only defect as to the disposition of their force; the right-aft guns were fired with much more difficulty than in the circular-sterned ships. Lieutenant James Coutts Crawford, (now a post-captain,) serving in the Prince, off Cadiz, in 1798, writes to a friend as follows:—"Many here complain of the want of strength in the construction of our ships' sterns, and also of their improper form for defence; for instance, in this ship (Prince) we cannot fire a gun from our lower deck out at the stern ports without materially injuring the lower counter, it is so flat, and overhangs so much; from the middle deck we cannot fire without cutting away a transom, that is placed so high that the guns cannot be pointed over it."

Among numerous instances of the want of defence in the square sterns, the following, given in Sir Robert Seppings's Letter on circular sterns, fully prove the fact. "When the Alexander, of 74 guns, was chased and captured by five French ships of the line, in 1794, after a most gallant resistance, she attempted, during the chase, to fire her stern guns, but with little success, as in no instance could the shot cross, and when the enemy laid on her quarter (or what is termed the point of impunity) she ceased to annoy her opponents."

"In the memorable action of Lord Howe, in 1794, and in other general actions, many of the ships suffered much after losing their masts, and thereby falling off, by which they were exposed to the fire of the enemy, without the means of defending themselves."

"During the war I believe that the following ships, among others, of the line, suffered very considerably in the Bay of Gibraltar, and on the coast of Spain, from gun-boats, namely, the Gibraltar, Northumberland, Terrible, and Powerful; and I believe the ships serving in the Baltic, secured and armed the stern in the best manner its form would admit, from a constant apprehension of attack in calms when passing the Belt; and the Minotaur and Dictator, it sppears, lost in killed and wounded many men by gun-boats raking them in a calm."

Instances of the same want of defence in the sterns and quarters of frigates also frequently occurred; in the actions of

the Blanche with La Pique, and the Phoenix with the Didon, it was particularly shown.

It appears that the repeated instances of the want of defence experienced in the sterns and quarters of our ships of war, convinced many naval officers of the necessity of a change in their form, in order to remedy this very serious defect. One of the present Commissioners of the Navy, who was a lieutenant in the action of the first of June, "drew a circular form for the stern, as the figure which would, under the circumstances above stated, have afforded them the means of bringing their quarter guns on the enemy, and thereby drawing off the fire which then annoyed them." Captain Larcom's opinion, who commanded the Prince off Cadiz, is given in the letter by Captain Crawford quoted above. He considered "that the stern of a man of war should be constructed like that of a Dutch fly-boat; that there should be ports all round, to enable you to fire in every direction, and from all the decks; that there should be no ornaments; and, as to conveniency, that there should be water-closets, as they have in West Indiamen, instead of quarter galleries."

The two principal defects in the defence afforded by the guns in square-sterned ships, appear to have been a difficulty, and, in some cases, an incapability of using some of the right aft guns, and the want of defence on the quarters. The first defect was to a considerable extent remedied in reducing the breadth of the seat-transoms, and diminishing the excessive overhanging of the counters and sterns. Some of the right aft guns were, however, even in the improved square sterns, prevented from running sufficiently out; so that the explosion took place too far within board, and the guns could not be sufficiently depressed.

The most important defect, however, of the square-sterned ships, was the want of guns on the quarters; and the question constantly presented itself, how could this defect be most properly removed?

The Christian VII., a Danish ship taken by the English, is frequently adduced as having possessed such a form, as to have fully answered the purpose of having quarter guns, by the after

part of the ship tapering inward. It appears that this ship certainly possessed the advantage of training the after-broadside guns, so as to point much further aft, than square-sterned ships of the general form. The capability of training the after-broadside guns in this ship, so as to bear as far aft as possible, will be compared with the capability of training the after-broadside guns of the old square sterns of the common form, and the quarter guns of the circular sterns, by which their relative efficiency with respect to the defence of the quarters will be seen.

Another method proposed for obviating this generally acknowledged defect of want of quarter guns, and which has been lately adopted in his Majesty's ship Sapphire, of 28 guns, constructed by Professor Inman, is, suddenly contracting the ship's sides at the quarters, and fitting the entrances to the galleries as ports, which, being on the angle of the quarters, admit the guns to be so trained, as to cross the fire of the stern guns. This obviates the defect of insufficiency of defence to a considerable extent, but has the same defects as the Christian VII. in leaving the mechanical weakness of the square stern still unobviated. In this plan the fittings of the quarter galleries must be made so as to be easily taken down, which in frigates and smaller vessels may be accomplished without much difficulty; but in two and three-decked ships, the difficulty of removing the quarter pieces and the other fittings, which it might be requisite to shift hastily, would be very great, even if practicable.

The only method which appeared likely fully to remove the two principal defects, weakness in the construction of the stern and insufficiency of defence, was the circular form of sterns, which was proposed by Sir Robert Seppings, and which was first adopted in the Aigle of 42 guns.

Fig. 29 shows the plan of the after part of the gun-deck of an eighty-four gun ship with the old square stern; Fig. 30 shows the plan of the after part of the gun-deck of the Christian VII.; and Fig. 31 shows the plan of the after part of the gun-deck of an eighty-four gun ship with a circular stern. By drawing on these plans lines representing the directions in

which the right-aft and after-broadside guns can be trained, and comparing them with the directions in which the guns of the circular stern can be trained, a comparison of their relative means of defence may be seen.

From the points A, in these figures, taken in the middle lines of the decks, at a distance A L, equal to $14\frac{1}{2}$ feet from the after-part of the sterns, as centres, with a radius A B equal to 40 feet, describe arcs of circles B C D E, to which the different bearings of the guns are referred.[1] The lines G D are drawn in the directions which show the greatest angles with a transverse line, to which the after-broadside guns can be trained to bear aft. The lines F C are drawn to show the greatest angles with a fore and aft line, to which the right-aft guns can be trained to bear forwards on the quarters; and the lines H I are drawn to show the greatest angles with a fore and aft line, to which the right-aft guns can be trained to bear on the other side of the ships' sterns. By referring these bearings to the arcs of the circle B C D E, circumscribing the sterns, it appears that in Fig. 29, representing the after part of the gun deck of a common square-sterned ship, every point in the arc E D is defended; that the arc D C is undefended, no gun being capable of being trained so as to bear on any point in this arc; and that the arc C B is defended by the right-aft guns; and that the arc B K is defended by the cross-fire of both the right-aft guns. The fires of the two right-aft guns cross at a distance from the stern L I, equal to 16 feet.

With respect to the undefended arc C D, it may be observed, that at the short distance at which this arc is drawn from the stern, the undefended space is very small, not being more than 28 feet; but as the lines F C and G D, representing the bearings of the right-aft gun and after-broadside gun, *diverge* from each other, the undefended space constantly increases in proportion to its distance from the stern; and as the angle of divergence of these bearings in this ship is $21\frac{1}{2}$ degrees, at a distance of half a mile from the stern, the undefended space, or

[1] This mode of illustrating a comparison of the defence afforded by these sterns, is adopted from Mr. Harvey's paper, before mentioned.

place of impunity, will be nearly 1000 feet, where ships may lie wholly out of the bearings of the guns, and by their unopposed fire may produce the most fatal effects on the stern and quarters of the ship.

In Fig. 30, representing the plan of the after part of the gun-deck of the Christian VII, the bearings of the after broadside and right-aft guns are shown by corresponding lines. The two lines F C and G D, which give the greatest training of the after broadside gun to bear aft, and of the right-aft gun to bear forward, approach more nearly to a parallel in this ship than in the common square stern Fig. 29, by an angle of 9½ degrees; so that the angle of divergency of these two directions, is only 12 degrees. The defended arc E D in this stern, Fig. 30, is 33 degrees, the undefended arc D C is 31 degrees, and the defended arc C B is 26 degrees. The fires of the two right-aft guns cross at a distance from the stern, L I, equal to 12 feet.

It appears, that by this mode of constructing the stern, contracting it greatly at the extremities, the undefended space on the quarters of the ship is considerably diminished, but still that this defect is not removed in this ship.

In Fig. 31, which represents the plan of the after part of the gun-deck of a round-sterned ship, the additional quarter port P is shown. The line G D in this figure shows the direction of the bearing of the quarter gun trained to point as far aft as possible, and F C shows the direction of the right-aft gun trained to point forward towards the quarter. It appears that these two guns cross their fire at C or D, which points coincide in this figure, 22 feet from the stern; so that the whole of the arc B C D E, is completely defended, there being no point in it, on which the fire of at least one gun can not be brought to bear. The fires of the two right-aft guns in this figure cross at a distance from the stern, L I, equal to 13½ feet.

	Common square stern.	Contracted stern of Christian VII.	Round Stern.
The arc E D	22½° Defended.	33° Defended.	53° Defended.
— D C	40½° Undefended.	31° Undefended.	0° point of cross fire.
— C B	27° Defended.	26° Defended.	37° Defended.
Defended arcs, E D and C B	49½°	59°	90°
Undefended arc, D C	40½°	31°	0°
The whole are, B C D E	90°	90°	90°

From this comparison of the defence of the three sterns, it appears, that the undefended arc of the contracted stern of the Christian VII, is less than that of the common square stern, by 9½ degrees, and that the whole of the arc circumscribing the round stern is completely defended at all points.

The Christian VII, however, does not appear to have possessed all the advantages with respect to the direction of fire of the after broadside gun, which might have been expected from contracting the stern so much aft. The after broadside port having its sides in an athwartship direction, prevented the gun being trained to point so far aft, as it might easily have been made to do, by making the sides of the port perpendicular to the curve of the side, or, as would have been better, by giving the direction of the after side of the port an inclination abaft the perpendicular. This ship appears also to have had no right-aft port on the upper deck. There is no doubt but that by constructing the sterns of ships according to this principle, contracting the sides greatly abaft, not only might the point of impunity be avoided, by the divergency of the directions of the after broadside and the right-aft guns being done away, but that the directions of the fire of these guns might be made to cross, although at a greater distance from the ship than with the round sterns.

The impropriety however of this form appears by considering,

that by the great contraction of the ship's sides abaft, the advantage of training the after broadside guns further aft, is obtained by the disadvantage, of not being able to train them, so as to point so far forward as is often found necessary; that the accommodation of the after cabins is greatly diminished by the contraction; and that the same defect of weakness arising from the principle of the form, remains as in the other square-sterned ships.

The result of a series of experiments made by Mr. Harvey on the comparative defence afforded by the square stern of the Hamadryad frigate, and by the circular stern of the Boadicea frigate, each mounting 46 guns, fully showed the great advantage of the form of the latter ship. He found that the undefended arc of the one side of the square stern was $32\frac{1}{2}$ degrees, and the defended arcs $69\frac{1}{2}$ degrees, the whole arc being 102 degrees, extending from the middle of the stern to the extreme bearing forward of the after broadside gun; while the whole arc was completely defended in the circular stern. The cross fire of the guns of the circular stern was also much greater than that of the square stern.

The reports of naval officers, who have commanded ships built with circular sterns, confirm the advantage of this form of construction. The Honourable Captain Spencer gives the following report to the Honourable Navy Board, dated 23d January, 1821, of the character of the Owen Glendower, of 42 guns, fitted with a circular stern. "I beg leave to acquaint you with the arrival of His Majesty's ship under my command, at this anchorage, (Valparaiso Bay,) after her passage round Cape Horn, during which passage she naturally experienced a good deal of bad weather, particularly during one heavy gale with a high sea up, she behaved very much to my satisfaction. The two stern boats were kept in their places over the stern during the passage, which in square-sterned ships is frequently not done; ours did not ship one drop of water during the time. In my opinion the only trial remaining to be made, is that of scudding before a very high sea, which we have never yet done. From having had reefed courses set during most of the time, I found it necessary not to brace the main-yard up with the after braces, as from the leading block being brought further for-

ward, and consequently the brace making a more acute angle with the main yard, it appeared likely to cripple it. I beg leave to refer to my former letters on this subject relative to the inconveniencies attending the cabin sashes, which were necessarily closed and caulked in during the whole passage, owing to their extreme leakiness and insufficiency to keep out both rain and sea; and I should suppose, that with scarcely any additional expense, a sort of shed, or something like it, might be fitted to keep the rain water from running in as it does. The ship in general is a remarkably easy one, but I think that after the bad weather she has experienced, and the press of sail I have carried on her, her not requiring any caulking must prove her stronger than the generality of ships." The following is the report of Captain F. A. Collier, dated 8th October, 1822, to the Navy Board, on the character of the Ganges of 84 guns, fitted with a round stern. "I have the honour to acknowledge the receipt of your lettter, requesting me to state whether I have any objection to the form of construction, as far as relates to the strength and proportion of the ship I have the honour to command. In reply to which I have to state, that off the Cape of Good Hope, we experienced a constant succession of severe gales for twenty-nine days; no vessel could behave better; I repeatedly wore her under the main stay sail only, that we might *be longer before the sea*, which was tremendous; she never threw the water even into the ward-room, and not a spray ever wet the stern-walk. I think a little improvement might be made as to the strength of the poop and cabin, which is the only part that worked: I could point it out much better than describe it on paper. We never had an opportunity of scudding; her log, which is at the Admiralty, will show how she performed; although so *very jury masted*, you will perceive 12 knots repeatedly on her log." The report of Vice-Admiral Sir Harry Neale, to the Honourable Navy Board, dated 18th April, 1825, on the Revenge of 80 guns, built with a circular stern is as follows:—"In compliance with your request that I should report my opinion upon the advantages obtained, or otherwise, by the construction of the circular stern, I beg to state, that from the experience acquired on board the Revenge, when her circular stern battery was used against some

gun-boats from Algiers, in July 1824, I had the most ample reason to be satisfied that the advantage obtained by that mode of construction was very considerable. Independently of the additional force acquired on the quarters, the present formation of the ports in the circular stern (serving also as windows) favours a more effectual use of the guns, by admitting generally of a greater degree of elevation and of depression, and also of commanding a more extended angle towards each quarter. The fire from the guns is with more safety extended without board than in the former construction, in which the transoms prevented the muzzles from reaching a secure distance without the ports, and not only comparatively limited the effectual use of the guns, and restricted the range of the shot, but this defect occasioned a liability of injury to the stern frame by the unavoidable concussion produced on firing them. When the Revenge was occupied off Algiers, five guns were placed over the stern and quarters in the poop cabin, which amounted to what is considered the whole of the stern battery on that deck. The guns below were similarly arranged in each port or window. The advantage of these batteries thus exhibited and employed against the enemy, was too clearly demonstrated to admit of doubt; and some officers who were not before satisfied of the utility of the circular construction of the stern, were fully convinced of the advantage obtained, and expressed their concurrence. I had occasion to direct the stern and quarter guns to be fired at the greatest elevation the carriages would admit of, and no injury to the stern frame was sustained by any concussion produced, or by the weight of metal. The starboard quarter guns were trained as close to the ship's side as the ports would allow; in consequence of which, the doors of the water-closets were injured, and the slight ornamental pieces which formed the pannels on the exterior of the closets on both decks, fastened only by brads, were shook off by the concussion. The lining to the awning that projects over the stern gallery, was also shook off, but no injury whatever occurred to any of the substantial work, and it must be recollected the guns were fired at the greatest elevation. The doors of the water-closets in the Revenge may be placed without inconvenience a few inches farther aft, by reducing the depth of the closet. The

trifling injuries, however, that occurred, are too insignificant for consideration, when compared with the service capable of being performed. I am decidedly of opinion that the circular stern is a very important improvement in the construction of ships of war, affording a more efficient means for defence, and also of strength to the fabric."

These reports are sufficiently satisfactory on the advantages resulting from circular sterns, as far as the experience of them has hitherto extended;—but it must be in war, that the advantages of this mode of construction will be fully known.

It may appear, that the main points of the question have been sufficiently considered; there are, however, objections brought against the adoption of circular sterns, which require to be examined. Independently of the objection, which has been alluded to, that an increase of defence in the square sterns and quarters of our ships of war, is unnecessary, it has been said, that such an increase of defence would tend to diminish the courage and confidence of our sailors. It is not, however, even hinted, that the defence afforded to ships of war by the guns in our square sterns has ever, in the least degree, had this effect: how, then, can the increase of this defence produce it? And if the defence of our ships by the right-aft guns has never given rise to the notion that our ships were constructed with a particular view to defence in running away from an enemy, how improbable is it that the disposition made to admit guns on the quarters of our ships, should give this notion. We consider, that not only will the complete defence of the sterns and quarters of our ships produce the most important advantages in engagements, but that there is every reason to believe, that a superior confidence in their security and power of attack and defence, will aid (if any thing can aid) the courage of British sailors.

Another objection brought against circular sterns is, that the after broadside gun is taken away, and substituted by the quarter gun, so that what is gained in one way is lost in another. Now this is totally unfounded, as the after broadside gun remains as in the square sterns, and the quarter port is altogether additional.

Another objection occasionally brought against the circular

sterns is, that the space of the after cabin is reduced by taking off the angles at the quarters. This is admitted; but at the same time it is true, that the diminution of space is very inconsiderable: and it must be remembered, that in line of battle ships, stern-walks are added, which are continued round the quarters, which the weakness of square sterns rendered it necessary to take away: this, probably, more than compensates, as to accommodation, for the diminution of room in the cabins of the square sterns,—independently of the advantage as to service, in affording convenience for observation. If, indeed, we add the space of the stern-walks to the space of the cabins of the circular stern, we find it altogether to be nearly equal to the space of the cabins of the square sterns; and if we compare the space of the cabins of the circular sterns without the stern-walks, with the space of the cabins of the Christian VII., contracted abaft to enable the after guns to be trained so as to bear more upon the quarters, it is found to be greater, by a space of upwards of 300 feet, than in that ship; so that this objection appears to be sufficiently removed; indeed, it is not very frequently urged.

The disposition of the water-closets was at first considered an objection to circular sterns, particularly in the ward-rooms of our ships; but the disposition of them has been altered, by removing them from the middle of the right-aft to the quarters, so that the principal part of the objection has been obviated. At one time the question of the advantage of circular sterns took too much the character of a question concerning water-closets. It must be admitted, that while the accommodation of every one engaged in the perilous duty of giving protection and adding to the honour of our country, is of great importance, it is particularly to be attended to for those officers, who, from age, and rank obtained by long and valuable services, are entitled to every consideration the nature of our service will admit of; yet the disposition of the water-closets cannot be considered as proper to take a prominent part in the examination of this very important change in the military character of our ships of war. The principal objections to the disposition of the water-closets are now removed, and various improvements, suggested by experience, are continually being made in

them. At all events, it does not appear that the disposition of the water-closets can ever be properly brought as an objection to circular sterns.

Another objection brought forward is, that the beauty of the circular sterns is much less than that of the square sterns. This, however, is altogether independent of the real importance of circular sterns. That they are not at present generally considered so handsome as some square sterns, is certainly true; but it must be observed, that it is difficult for us to compare their appearance without being prejudiced in favour of the form we have so long been accustomed to admire. If we take the late stern of the Nelson as an example of the beauty of square sterns, we shall have a specimen far above their average appearance, as it was the result of the particular attention of the builder; and all who examined it were much pleased with the excellency of its carved work and workmanship: yet even in this stern, pleasing as the general appearance certainly was, if we attempt to analyze its design, we cannot but admit that raking pillars, supported by eagles, with other incongruities, rendered its design incapable of being strictly examined according to the analogy of architectural beauty. Indeed, the necessity of placing pillars inclined to the "tumbling home" of the stern, in order to render the appearance what is termed "ship-shaped," is a defect which the nature of ships' sterns renders it very difficult to avoid. The contrary flexure in the outline of the circular sterns, when viewed from a short distance, gives an appearance of irregularity in the sashes, arising from their being worked to the different curves, which appears to be opposed to the beauty of outline of the round aft of the stern; but as the main objects of the circular sterns (their increased strength and defence) are now effectually obtained, the general beauty of the stern may be more particularly attended to, and such improvements as the experience and taste of the constructor may suggest will no doubt be gradually made. In the opinion of many, the circular sterns of the Princess Charlotte, Hibernia, and several other ships, present so pleasing an appearance, as to rank even for beauty with most of the square sterns in the service.

In addition to the removal of the two great defects of square

sterns, (weakness of the stern-frame, and want of defence,) the circular sterns possess several other advantages, which, although subordinate to these two principal points of improvement, are of considerable importance, particularly the diminution of the quantity of materials in the circular sterns, compared with the quantity of materials in the square sterns, as affecting both their weight and expense of construction.

The weights of all the materials, timber, iron, and copper, of a circular and square stern of two three-decked ships of the same class, have been carefully obtained,[1] taken from a transverse vertical plane at the after part of the after broadside port on the middle deck, at which place the variation in the two sterns commences.

	Tons.
Weight of the square stern	194.8
" circular stern	185.0
Weight by which the circular stern is lighter than the square stern	9.8

The momentum of the weight of the circular stern is not only less than the momentum of the square stern by the diminution of the weight, but also by centre of gravity of the circular stern being further forward than the centre of gravity of the square stern. In consequence of the diminution of the momentum of the weight of the stern of the ship, the strain on the after part of the ship, occasioned by the inadequate support afforded to this fine part of the body by the vertical pressure of the water, is reduced, so that the tendency of the after part of the ship to break its sheer, or 'hog,' is less in ships with circular sterns than in ships with square sterns.

An advantage is also obtained by this diminution of the weight of the stern, with respect to 'scending, which is an important consideration in the sailing qualities of the ship.

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[1] These results were obtained from measurements and calculations made by Mr. Bennett, to whom this Work is indebted for two Papers, Art. XIV, and XXXVII.

A considerable advantage in this mode of construction is, that most of the large timber of great curvature, which was necessary in the square sterns, and which it was found very difficult to obtain, is not required in circular sterns. The substitution of vertical timbers in the improved square sterns, for the transoms below the transom in the old square sterns, was of great benefit in this respect; but a considerable quantity of large "compass" timber was required, even in these improved sterns, which is not required in the circular sterns.

The expense of the circular and square sterns may be compared with respect to the kind and quantity of the materials used in their construction. The expense of the materials of the circular sterns is less than the expense of the materials in the square, on two accounts: the diminution of the quantity, as just shown in the preceding example; and by the price of the straight timber being less than that of "compass" timber, for which it is substituted. With respect to the expense of the workmanship of the two methods of constructing the sterns, it may be observed, that when circular sterns were first introduced, before the officers and workmen became well acquainted with the practical detail of this mode of construction, the expense of the workmanship was considerably greater than at present, the plan being now fully understood; and owing also to the alterations always necessary to be made in carrying into execution any considerable improvement. The most difficult pieces of workmanship in the construction of a stern-frame are now given up by the introduction of the circular form: the whole of the workmanship, when properly understood, being of a very simple and easy kind. The total expense of the circular stern is therefore, on the whole, *considerably* less than that of the square stern, the expense being less both for the materials and workmanship.

Another very important advantage in the circular sterns is, that the stern-frame is now timbered all round, leaving only such openings as are necessary for the guns and windows; so that the defence is greatly improved from the destructive effect of a raking fire from an enemy, from which the great quantity of glass-work in the square sterns afforded no defence.

The stern being timbered all round will also be found very

advantageous, when a ship is scudding and a sea breaks over the stern, which will be prevented from breaking into the cabins in such great quantities as are admitted by the large openings in the square sterns. The circular stern, when the ship is pooped, by its increased strength, will also sustain the strain of the sea so as to be much less weakened by it, than the square stern.

In conclusion, it may be observed, that most other nations have adopted this alteration in the form of their ships of war, which affords a strong additional presumption of the importance of this improvement. Mr. Dupin, Member of the Royal Institute of France, speaking of this improvement, observes, "But above all, it is in the sterns of their ships that the English, at this time, carry into effect a great improvement. For the future, the sterns of their ships of the line and frigates are to be circular, composed of timber, and planked up in the same manner as the sides of the ships."—"The weakness of our sterns, and the advantage of closing them, by circular or square bulwarks, were among the evidences continually striking those who have well appreciated the force of our ships of war. Forfait and M. Rolland have made models of close circular sterns for large ships. M. Montgery, towards the end of the last war, gave also a plan of the upper works of a ship with a close round stern."—"I ardently wish to see these improvements, which have been enumerated, introduced into our ships. I have constantly repeated, since my first journey to England until this day, every argument, every observation, every experiment, which have appeared to carry conviction to the mind. Prejudices and objections which it is impossible to overcome, except by the aid of time, have presented themselves, but over these time will necessarily triumph."

It is the full conviction of the writer of these remarks, that the advantages of circular sterns will ensure their general adoption, and that this form will continue to be the general form of ships of war, for frigates as well as for line-of-battle ships;—for the latter of which it is most particularly adapted.

Several plans of circular sterns have been proposed since their introduction into His Majesty's ships of war, differing in various minor points: the main points are, however, obtained

in all of them, no alteration of material importance having been proposed in any.

No doubt experience and taste will gradually suggest many improvements in circular sterns; but the great points of an increased defence and strength of the fabric having been efficiently obtained by the original proposer, all improvements that may be made must be considered altogether subordinate to these main objects. One of the plans at first thought of, the writer of these remarks has understood to have been, to have had the circular sterns without any of the external galleries for water-closets, which would have been fitted in-board: this plan would have obviated the objection of the inflected curve of the stern, while it would have allowed light balconies for walking round the stern; probably fitted so as to be easily shifted. The objection to this plan was, that the head of the rudder would have been exposed, or at least more in the sight of an enemy. Whether, however, this objection may be removed, and such a form may be thought worthy of trial, is a question, which the proposer of circular sterns, who has paid most attention to the subject, is best qualified to decide on.

It is not, however, the intention of this Paper to compare the respective advantages of different circular sterns, but to examine their general excellency. An impartial examination of the effects produced by constructing ships with circular sterns instead of square sterns, appears to prove, that the defects which experience has long felt that the square sterns of ships of war possessed, have been fully removed; and that if there be any defects, either as to appearance or utility, in the circular sterns, which yet remain to be removed, that they sink into complete insignificance, when compared with the numerous and important advantages which His Majesty's ships of war have obtained by the very valuable improvement of the circular form of their sterns.

I cannot close these remarks on the comparative advantages of the square and circular forms of ships' sterns better, than by quoting the concluding paragraph of Mr. Harvey's paper. He observes, "In concluding the present Paper, I cannot refrain from expressing my decided conviction, that the adoption of the curvilineal stern not only increases in a very considerable

degree the means of defence in every ship to which it is applied, but also adds very much to the mechanical strength of her frame, and that it would be folly to abandon a form which has so many legitimate claims on our attention, from any undue and improper attachment to one which has unquestionably nothing to recommend it but custom and time. In the changes that are daily taking place around us, from the new and ever-varying improvements in the mechanical arts, and to which our country, at the present time, owes so much of her welfare, prosperity, and power, we may draw innumerable maxims to prove the impropriety of chaining ourselves to systems, which have nothing but the authority of time to recommend them, and from which science withdraws her countenance and support. The present, indeed, is an age of brilliant and unbounded improvement; and every day brings us new accessions of knowledge, and new triumphs of genius, over the obstacles of nature; and therefore Naval Architecture, which is but just emerging from the slumber of ages, and from the trammels of imperfect and antiquated rules, ought by no means to be checked in its career. The present time, also, is one peculiarly auspicious for an inquiry of this kind. Peace and tranquillity extend every where; and we have just that degree of naval activity that will enable us silently, but effectually, to carry into our marine every improvement that the enlarged experience and science of modern times can afford,—to increase to the utmost the mechanical strength and the means of defence of our floating bulwarks, and likewise the means of navigating them securely across the uncertain bosom of the deep."

M.

Art. XLI.—*Remarks on* Art. XXXIII. *in the last Number of "Papers on Naval Architecture;" "On the Position of the Centre of Effort of the Wind on the Sails," &c.; by* Mr. W. H. Henwood.

In the seventh article of "Papers on Naval Architecture," it is stated, that "when a ship is sailing by the wind, as the particles of air impinge very obliquely on the surface of the

sails, and as each particle in gliding off after impact, takes off a part of the action of some of the more leewardly particles, the effective action of the wind on the sails, must be gradually diminished from the weather-side to the lee-side.

The manner in which the particles of air act upon the sails, when a ship is close hauled, is, it is probable, analogous to the manner in which the particles of water act on the leeward-side of the bottom, in the same circumstances. It would seem, by parity of reasoning, that as the particles of water impinge more or less obliquely on the bow, gripe, and fore part of the keel on the lee-side; and as each particle in gliding off after impact, must take off a part of the action of some of those which strike the body farther aft, the effective resistance of the water on the leeward-side of the bottom of a ship, must be gradually diminished from the stem to the sternpost. This may not be the case on the weather-side; the negative resistance to a ship's motion, arising from the diminution of pressure on this side, is perhaps the greatest wherever the horizontal sections of the bottom are the least inclined to the line of leeway, or to the direction in which the ship moves a-head.

It is presumed it will be admitted, that by far the greater portion of the lateral resistance which a ship experiences when sailing by the wind, must be produced by the force of the water on the lee-side; and that the impulses of the elementary particles of the water, on the greater part of the bottom of a ship, must necessarily take place in horizontal lines.

Supposing this to be the fact, it may be inferred, that whether a ship is full or sharp, forward or abaft, she would be more weatherly if made to sail on an even keel, than she would be if caused to swim by the stern, through an addition being made to the depth of the keel at the after-end; the stream of water below the horizontal depth of the gripe, would act with at least as much force on the part added below the after-end of the keel, as the water forward strikes with on the forefoot. This appears to explain why a cutter, or any other vessel, which has a much greater draught of water at the stern than at the head, must have the centre of effort of her sails very far aft.

A ship that is unusually full forward and fine abaft, and

which has little or no difference of draught of water, cannot, it is imagined, be weatherly, in comparison with other ships, through the effect produced by the resistance of the water on the lee-side. According to Lieutenant Carlsund, the ardency of Chapman's frigate, which was very full forward, and very fine abaft, "must have been in consequence of the diminished adhesion of the water to the after-body, as the shape of the fore part would, according to the common theory, have had the contrary effect." He afterwards remarks, that "the common notion that the full fore body carries the mean resistance further aft, is not true in general."

It is proper to ask, if this common notion is erroneous, why should the weatherly qualities of the frigate be attributed to the shape of the after body, rather than to the fulness of the ship forward? And why is this common theory referred to as though it were true, and afforded as proof that the ardency of the frigate had been ascribed to its proper cause? If a full fore-body does not carry the mean resistance farther aft, it is reasonable to conclude that it must carry it farther forward, as it would be absurd to suppose the position of the mean direction of the resistance to be independent of the form given to the fore part of the ship.

That the ardency of the frigate was owing to the diminished adhesion of the water to the after-body, is by no means obvious. It is considered that the friction or adhesion on the after-body, must always be greatest where the horizontal lines on the surface of the bottom coincide most nearly with a fore-and-aft direction, and that it must diminish in proportion as the surface is less inclined to the direction of the ship's course. If this be conceded, it will follow, there must be more adhesion on a fine after-body than on a full one. According to Lieut. Carlsund, the adhesion "on the windward side of the after-body diminishes the lateral pressure in that part, and in a greater degree when the vessel is full aft than when she is lean;" so that the greater the adhesion the less must be the lateral pressure, and vice versâ. But it seems natural to suppose that great pressure must always produce great adhesion: and, as it is admitted there is less lateral pressure when the after-body is full; if it also be true, there is greater lateral

pressure when the after-body is lean, and that great pressure necessarily occasions great friction, or adhesion; it certainly must be accurate to say, the ardency of the frigate "must have been in consequence of the diminished adhesion," as the adhesion could not but have been comparatively great.

That there is less lateral pressure on a full, than on a fine after-body, is highly probable from the slow sailing of ships which are uncommonly full aft. The want of pressure, or the negative resistance, is, in such ships, greater than in others.

It is not improbable the ardency of the frigate in question may have been, in some measure, in consequence of the water towards the stern, on the weather side, acting, or collapsing on this part of the ship with greater force, or more perpendicularly to the line of the ship's motion, than it would have done if the after-body had been full. And perhaps the fulness of the fore-body, by causing a greater adhesion of the fluid in passing round the weather-bow, might also have had some influence in rendering her weatherly. Also, it is to be supposed, the centre of gravity of this frigate must have been situated very far forward; and if she was brought to her proper draught of water by ballast, guns, and other heavy articles, placed too near the bow, this, by causing her to pitch heavily, would, necessarily, increase the ardency.

It may just be remarked that Lieut. Carlsund has not proved his assertion, that the "common notion," above referred to, "is not true in general;" and that until this shall have been done, there is reason to believe that, as a plane surface invariably meets with more resistance than a convex one, when moving in water, so the sharpness of a ship forward, abstractedly considered, must always have the effect of augmenting the ardency. It may too be mentioned, that nothing can be concluded respecting the effect of a very full fore-body, and great rake of stern, when the after-body is lean, and the masts are placed in the usual manner, unless other minutiæ, which likewise have a considerable influence in making a ship ardent, had been particularized.

The truth of hypotheses concerning the resistance of the water, may, probably, as Lieut. Carlsund has hinted, be ascer-

tained by means of observation and experiment on the effects of the force of the wind on the sails.

It appears from experiment, that the oblique action of a fluid on a vertical and plane surface is not concentrated in the centre of gravity of the surface, unless the velocity of the fluid is indefinitely small; and it is accordingly inferred, that the actual position of the centre of the resistance of a fluid on a surface, or of the wind on a sail, is dependent on the rapidity with which the fluid moves, relatively to the resisted surface. It was shown, in the paper already referred to, that the centre of effort of the wind on a sail which is trimmed sharp, is always on the windward side of its centre of gravity; and as it is impossible to say how far apart the common centre of effort of a ship's sails, and their common centre of gravity are situated when the ship is close hauled, and the wind is strong, it is considered desirable the actual relative positions of those points should, if possible, be ascertained by experiment.

To a scientific individual, who has the command of a ship, it is thought it would not be an invincible difficulty to find, by experiment, the true position of the vertical line, to which the centre of the oblique action of the wind on a sail is usually approximate. Could this first be determined, a series of adjustments of the sails of a ship, that they might balance the efforts of the water on the bottom, in a variety of states both of the wind and the sea, would in all probability enable us to arrive at a satisfactory conclusion, concerning the manner, in which the mean direction of the resistance of the water on the bottom is affected by variations of the surface of the sails, and strength of the wind.

Respecting the reasons which Lieut. Carlsund assigns, why "the centre of effort of the sails which are used in strong winds ought to be further forward than that of the sails used in light winds," because of "the greater inclination of the vessel," and also on account of "the greater curvature of the sails," which, he says, has a tendency to bring the centre of effort of each sail further off; it may be remarked, first, that since when a ship heels, the centre of effort of each sail, together with that of all the sails, revolve in vertical transverse planes about the

longitudinal axis of the vessel, which passes horizontally through the centre of gravity, it is quite evident the inclination of the ship can have no effect whatever in removing the centre of effort of the sails either forward or aft; and, secondly, that as when a ship is much inclined by a strong wind, which produces a great degree of curvature in the sails, the particles of air pass along the surface of each sail in horizontal lines, which are neither parallel to the yards nor perpendicular to the masts, and which have less curvature than those lines have which are parallel to the yards, it is by no means certain that a greater degree of curvature of the sails, when it is accompanied with a corresponding inclination of the vessel, can have a tendency to change the position of the point in question. The passage of the particles of air across the surface of a sail, may, on account of the difference of inclination of the vessel, be made in lines equally curved, whether the wind be moderate or excessively strong.

The reason why the centre of effort of the sails, made use of in strong winds, should be farther forward than that of those employed in light winds, must rather, it is conjectured, be explained by supposing, that in proportion as the velocity with which a ship moves a-head increases; and according as the water acts with greater force on the lee-bow, through the pitching of the ship; so with the mean direction of the resistance on the bottom, pass farther forward. And the reason why some ships, which carry their helms to windward in smooth water, carry them to leeward when the sea is rough, may perhaps be, that, owing to their bows being unusually full, they have not such a proportion of heavy articles forward as it is absolutely necessary they should have, in order to preserve a constant equilibrium between the resistance on the bottom, and the force of the sails.

What Lieut. Carlsund means by saying that "the effects produced by the difference of form of the fore and after-bodies may be measured by their relative fulness, by the application of the parabolic method of comparing vessels," it is difficult to discover. The relative fulness may be measured, and may be represented by two lines; but the effects produced by this

relative fulness, or difference of form, cannot be estimated in the present state of hydrodynamical science.

The parabolic system is undeniably a most ingenious method of producing the outline of the body of a ship; and if it could be ascertained, that the excellence of ships does not depend on small dissimilarities of shape, this mode of constructing ships might be adopted for the sake of a frugal saving of time and trouble. But it is proper to observe, that although a ship constructed by the parabolic method might be as good as those which were made the basis of the calculations from which the requisite formulæ were derived, there cannot be the shadow of a reason for supposing that a better vessel would be produced. If therefore this system were to be universally adopted, there could be no hope of improvement in the fundamental part of the science of Naval Architecture.

ART. XLII.—*Continuation of Dimensions and calculated Elements of Foreign Ships.* (From page 68.)

PRINCIPAL dimensions, &c., &c., of a Danish brig, mounting 12 guns, carrying ball of 19,6 lbs. English weight.

Draught of water forward, 10,5 feet; abaft, 12,3 feet.

Length on the water-line, 89,63 feet.

Breadth to the outside of the timbers at the midship section, 24,72 feet.

Breadth ditto at the wing-transom, 15,98 feet.

Depth in hold, 13,4 feet.

Height of the midship port above the water, 4,63 feet.

Area of the midship section, 156 square feet.

Centre of gravity of the midship section, 3,672 feet below the water-line.

Area of the load-water section, 1771,5 square feet.

Centre of gravity of the load-water section, 1,104 feet before the middle of the length.

Displacement, in cubic feet, 9249,7.

Displacement of the foremost third of the length, 2022,4 cubic feet.

Ditto of the middle third, 4470,6 ditto.

Ditto of the aftermost third, 2756,8 ditto.

Centre of gravity of the displacement, 2,36 feet before the middle of the water-line.

Ditto ditto, 3,374 feet below the water-line.

Height of the metacentre above the centre of gravity of the displacement, 7,87 feet.

Height of the metacentre above the water-line, 4,496 feet.

Area of the sails, 7925,8 square feet.

Height of the centre of effort of the wind on the sails, above the water-line, 36,86 feet.

Horizontal distance of the centre of effort before the centre of gravity of the ship, 4,48 feet.

Total number of the crew, 70 men, including officers.

To carry three months' provisions and stores.

The quantity of ballast, 900 pigs, each weighing 109,09 lbs.

Fifty rounds of shot and ammunition.

The weight of each gun, 16.7 cwt.

Three anchors, each weighing 14 cwt. 2 qrs.; and two, each weighing 4 cwt.

DIMENSIONS OF THE MASTS AND YARDS.

DIMENSIONS OF THE MASTS.				DIMENSIONS OF THE YARDS.			
	Extreme Length.	Diameter.	Length of the Head.		Extreme Length.	Diameter.	Length of Yard-Arms.
	Feet.	Inches.	Feet.		Feet.	Inches.	Feet.
Main	58,7	18,5	7,98	Main	47,4	11,0	4,83
Main-top	32,4	10,	4,83	Main-top-sail	38,3	8,2	7,7
Main-top-gallant	18,5	5,4	2,57	Main-top-gallant	24,7	4,6	3,6
Fore	51,5	16,8	7,2	Fore	43,3	10,0	4,12
Fore-top	29,9	9,25	4,55	Fore-top-sail	35,0	7,47	7,22
Fore-top-gallant	17,6	5,18	2,33	Fore-top-gallant	22,7	4,12	3,4
Bowsprit	38,6	18,5	14,1	Driver-boom	51,5	11,33	2,32
Jib-boom	28,4	8,2	13,	Gaff	37,2	8,75	6,15

The relation between the length of the water-line, and the distance of its middle point abaft the centre of the fore-mast, is ,3124.

Ditto, before the centre of the main-mast, is ,0929.

NAME OF THE VESSEL	Frigate.	L' Astrée Frigate.	La Romaine Frigate.	La Bachante Corvette.	Corvette.	La Victorieuse Brig.	Corvette.
NAME OF THE CONSTRUCTOR	Lamsthé.	La Mothe.	Forfait.	Le Tellier.	La Fosse.	Forfait.	Rolland.
	No. Pdrs.	No. Pdrs.	No. Pdrs.	No. Pdrs.	No. Pdrs.	No. Pdrs.	No. Pdrs.
NUMBER OF GUNS AND WEIGHT OF METAL	28 18	28 18	24 24	20 18	20 8	12 12	16 6
	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
Length on the water-line	144.42	135.83	139.67	124.	111.12	97.2	98.17
Moulded breadth	36.67	34.50	36.33	30.	30.624	25.6	25.
Depth in hold	19.25	18.	18.	14.10	15.5	12.9	11.
Draught of water in midships, to the upper edge of the rabbet of the keel	15.25	13.75	14.25	11.10	11.63	9.9	9.0
Height of the midship port from the water	6.	6.	6.	5.	——	4.1	3.50
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
Displacement, not including the plank	1423.18	1101.94	1071.44	796.164	742.97	475.172	387.00
Displacement before the middle of the length	801.16	610.89	597.47	450.183	379.01	250.064	208.17
Displacement abaft the middle of the length	622.16	491.04	473.97	345.181	328.96	225.108	178.03
Proportion between the displacement and the circumscribed parallelopiped	.49	.481	.499	.5	.501	.550	.493
Proportion between the midship section and the circumscribed parallelogram	.74	.759	.714	.713	.756	.780	.670
Proportion between the load water section and the circumscribed parallelogram	.83	.800	.793	.854	.816	.830	.815
	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
Centre of gravity of the displacement before the middle of the length	5.42	4.268	5.464	4.93	2.38	1.955	2.474
Centre of gravity of the displacement below the water-line	5.583	5.098	4.508	4.37	4.36	3.753	3.374
Metacentre above the centre of gravity of the displacement	11.501	10.553	13.112	9.65	10.016	7.59	8.543
Centre of gravity of the midship section below the water-line	6.182	5.692	5.842	4.728	4.810	4.08	3.721
Centre of gravity of the load-water section before the middle	2.09	1.355	1.999	1.638	.889	.720	.987

NAME OF THE VESSEL	Le Tonnant.	La Valeureuse Frigate.	La Fortunée Frigate.	La Tourterelle Frigate.	La Gracieuse.	L' Aurore.	La Gallene.
NAME OF THE CONSTRUCTOR	Borda.	Le Tellier.	Forfait.	Forfait.	Grognard.	LeTellier.	Olivier.
NUMBER OF GUNS, AND WEIGHT OF METAL	No. Pdrs. 80	No. Pdrs. 28 18	No. Pdrs. 26 12	No. Pdrs. 24 8	No. Pdrs. 16 6	No. Pdrs. 16 8	No. Pdrs. 12 4
	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
Length on the water-line	180.	147.	135.	117.175	98.50	90.	83.11
Moulded breadth	47.	36.167	34.67	29.17	26.	26.6	22.
Depth in the hold	23.5	18.	17.66	14.50	13.08	13.2	9.00
Draught of water in midships, to the upper edge of the rabbet of the keel	20.50	14.	13.42	11.	9.67	10.	6.33
Height of the midship port from the water	5.50	6.	6.	5.	5.	4.9	4.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
Displacement, not including the plank	3597.51	1262.93	1113.606	656.98	399.135	378.656	163.411
Displacement before the middle of the length	1934.47	710.35	619.754	368.42	210.170	216.06	95.298
Displacement abaft the middle of the length	1663.04	544.57	493.352	288.509	188.157	162.59	68.113
Proportion between the displacement, and the circumscribed parallelopiped	.581	.477	.494	.485	.453	——	.393
Proportion between the midship section and the circumscribed parallelogram	.853	.677	.727	.735	.720	——	.706
Proportion between the load water section and the circumscribed parallelogram	.876	.806	.813	.866	.788	——	.697
	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
Centre of gravity of the displacement before the middle of the length	4.49	6.032	4.519	4.672	2.444	3.782	3.673
Centre of gravity of the displacement below the water-line	8.733	5.001	4.96	4.135	3.22	3.505	2.256
Metacentre above the centre of gravity of the displacement	12.88	11.257	10.78	8.858	8.51	8.83	9.408
Centre of gravity of the midship section below the water-line	8.861	5.370	5.425	4.48	3.929	——	2.505
Centre of gravity of the load-water section before the middle	.649	1.719	2.564	2.115	.640	——	2.743

ART. XLIII.—*On circumstances attendant on a Ship's inclination from its upright position.*

EASY and regular motion, when a ship inclines from its upright position, is of considerable importance to the sailing qualities, and to the strength of the fabric. Independently of the effect produced, by the relative dimensions of a ship, its form within the limits of the immersion and emersion, and the disposition of the weights, in determining the measure of the stability at different angles of inclination, so that a ship may be restored to its upright position without being acted on too suddenly, and in regulating the depth and time of rolling, there are other circumstances to be considered in connexion with these elements, which influence greatly, though subordinately, the excellency of a design.

When a ship is inclined by the force of the wind or waves, it is frequently found that it revolves round a diagonal axis, when the inclining force is exerted in a transverse direction, arising from the relation of some of the elements of the design. When the direction of the inclining force is oblique to the middle line of the ship, this diagonal revolution of the ship is necessarily caused, and cannot be prevented by any arrangement of the design. Another circumstance frequently attendant on a ship's heeling, is a rising and falling of the ship, which is also dependant on some of the elements of the design.

By considering these two circumstances separately, and in immediate connexion with the elements of design on which they depend, their effects may be most clearly seen.

First, with respect to the revolution of a ship round a diagonal axis. When a body floats with permanent stability at any plane of floatation, the mean vertical pressure of the water, acting through the centre of gravity of the displacement, passes also through the centre of gravity of the body. When the body inclines, the centre of gravity of the displacement is carried over in the direction of the centre of gravity of the part immersed by the inclination, a distance inversely proportional to the total volume displaced and the volume immersed by the inclination; and the vertical pressure of the

water always acting through the centre of gravity of the displacement, causes the body to revolve round an axis, which is determined by drawing a line through the centre of gravity of the body in a horizontal plane, at right angles to a line drawn from the centre of gravity to the point where the vertical pressure of the water meets this plane. To render this axis longitudinal, it is necessary, that the centre of gravity of the volume immersed by the inclination should be in the same transverse plane, at all angles of inclination, with the centre of gravity of the volume emerged. This would cause the centre of gravity of displacement to move in the same transverse plane in which it was situated when the ship was upright, in which plane is also situated the centre of gravity of the ship; so that the axis, drawn in a horizontal plane at right angles to the line joining the point, where the vertical pressure of the water, passing through the centre of gravity of displacement when inclined, meets this plane, and the centre of gravity of the ship, would be in the direction of the middle line of the ship.

When this is not attended to in the design of a ship, it is liable to revolve round different horizontal axes, inclined at various angles to the longitudinal plane. That the centres of gravity of the immersion and emersion may be in the same plane, can be determined only by calculation.

Chapman alludes obscurely to this circumstance in the fourth chapter of his "*Traité de la Construction des Vaisseaux,*" where he observes, (Dr. Inman's translation, Art. 44,) "that the centre of gravity of the load-water line and that of the ship, should be in the same vertical line; for, when the ship sails close to the wind, and is inclined on one side, if the load-water line is fuller aft than forward, since the ship must preserve the same quantity of displacement, it will have an inclination also forward." Although Chapman appears by this remark to be acquainted with the fact, that ships are liable to this irregular motion, he was evidently so unacquainted with its cause, that he assigned means to prevent it which can have no influence whatever on it; as the centres of gravity of the load-water line and of the displacement may be in the same vertical line, and the ship when inclined equally subject to this diagonal pitching. In fact, it generally happens that the centre of gravity of the load-water

section and the centre of gravity of the displacement are not in the same vertical line, whether a ship be properly balanced in respect to this motion or not.

Atwood, in his Paper in the Philosophical Transactions of the Royal Society, of 1796, on the determination of the positions of the floating bodies, showed himself fully acquainted with the true cause of this irregular motion to which ships are subject. He says, (page 124,) "Another observation occurs on this subject. The entire stability of a ship has been shown to consist of the aggregate stabilities of the several vertical sections into which it can be divided. Let it be supposed that the ship has been inclined round the longer axis through a given angle, and that the vessel returns through the same angle of inclination by the force of its stability; if the forces arising from the several sections do not act in their due proportion on each side of the centre of gravity, in respect to the longer axis, the ship will not return to its position of equilibrium by revolving round the longer axis; but will be inclined round various successive horizontal lines between the longer and shorter axes; a circumstance that must create irregular motions and impulses, to which a vessel in all respects well constructed is not liable."

Dr. Inman appears to have been the first who has applied the true means of correcting this error to the actual design of ships; by giving the sides of the ship such forms within the limits of the immersion and emersion, consistent with other considerations, as to bring the centres of gravity of the immersed and emerged volumes, in, or very nearly, in a transverse plane.

By comparing the reports made on different ships in his Majesty's Navy, with calculations made on their drawings, it appears that those ships have the best character for regular and easy motion, *ceteris paribus,* that have their elements so determined, that the centres of gravity of the parts immersed and emerged by inclination, are in a plane nearest to a transverse plane. The Bulwark, whose character was very good in this respect, had the centre of gravity of the immersion at an angle of ten degrees inclination, only six inches in a fore and aft direction from the centre of gravity of the emersion; while the distance between these centres of gravity in some

ships that have been remarked for their uneasy motion, as to this diagonal pitching, has been from three to four feet.

By examining the results of the calculations made on foreign ships, (see Results of calculated Elements of Foreign Ships, page 64, in the first Number of this Work,) this relation between the centres of gravity of the volumes immersed and emerged by inclination, appears to be neglected. English ships appear to be the first that have been designed with proper attention to this subject; which, although not one of the necessary considerations in the design, is yet of sufficient importance to render it very desirable that it should be carefully attended to; as it is one of those considerations in the design of ships which tend to the excellency of this science.

The other circumstance attendant on a ship's rolling, is the rising and falling of the ship. This is caused by the tendency of a ship to roll into the water a volume greater or less than the part emerged by the inclination, dependent on the situation of the centre of gravity of the ship, and the form of the sides of the ship within the limits of the immersion and emersion. This rising or falling, which takes place during the whole time of the ship's inclining and returning to its upright position, and is therefore gradual, is yet sufficiently quick to increase in a considerable degree the strain caused by the rolling.

Let A C E (Fig. 32) represent the transverse section of a ship, A B being the water-line when the ship is upright; let G be the situation of the centre of gravity of the ship, round a horizontal axis, passing through which point, the ship is supposed to revolve. Through the point g, the intersection of the lines A B and C G, draw D E, making the angle A g D equal to the angle of inclination the ship is supposed to take by rolling; then if the volume B g E, which is immersed in consequence of the inclination, is equal to the volume A g D, which is emerged by the inclination, D E will be the true water-line, when the ship is inclined to the given angle, the total volume displaced after the inclination, D C E, being equal to the total volume displaced, A C B, when the ship is upright.

But if the volume immersed by the inclination, B g E, is *greater* than the volume emerged, A g D, the true water-line

after the inclination, M N, will be below D E such a distance, as to cut off the volume immersed B I N, equal to the volume emerged, A I M. If, on the contrary, the volume B g E is *less* than the volume A g D, the true water-line after the inclination, O P, will be above D E such a distance as to cut off the volume immersed, B R P, equal to the volume emerged A R O.

Supposing the sides of the ship (Fig. 33) within the limits of the immersion and emersion to be parallel to the plane of the masts, the volumes immersed and emerged by the inclination, B g E and A g D, will be equal, and consequently the total displacements equal, when the inclined water-line D E cuts the water-line when upright A B, in its intersection with the middle line G C. If in this case the centre of gravity is above the water-line, as at G, the ship will sink when inclined a distance equal to the difference between the lines G g and G Q; if the centre of gravity is in the water-line at g, the ship will neither rise nor fall; and if the centre of gravity is below the water-line, as at γ, the vessel will rise a distance equal to the difference between the lines γg and γq.

Supposing the sides of a ship (Fig. 34) to be parallel to the plane of the masts below the water's surface A B, and falling out above as B E and A L, the volume immersed, B g E, at the water-line D E, will be greater than the volume emerged, A g D; so that the true water-line M N, which cuts off the volume immersed B I N, equal to the volume emerged A I M, will be below D E, a distance dependent on the angle of the falling out of the ship's sides above the water. When the centre of gravity, in this case, is above the water-line, as at G, the ship will rise or fall according as G g is greater or less than G H; when the centre of gravity is in the water-line, as at g, the ship will rise a distance H Q; and when the centre of gravity is below the water-line, as at γ, the ship will rise a distance equal to the difference between γg and γh.

If the sides of a ship were parallel to the plane of the masts above the water-line, and fell out below, the effect would be directly contrary to that in the last case.

Supposing the sides of a ship (Fig. 35) to be parallel to the plane of the masts below the water's surface A B, and falling in above, as B R and A L, the volume emersed, B g E, at the

water-line D E, will be less than the volume emerged A g D; so that the true water-line O P, which cuts off the volume immersed B K P, equal to the volume emerged A K O, will be above D E, a distance dependant on the angle of the falling in of the ship's sides above the water. When the centre of gravity, in this case, is above the water-line, as at G, the ship will fall a distance equal to the difference between G g and G F; when the centre of gravity is in the water-line, as at g, the ship will fall a distance Q F; and when the centre of gravity is below the water-line, as at γ, the ship will rise or fall according as γg is greater or less than γf.

If the sides of a ship were parallel to the plane of the masts above the water-line, and fell in below, the effect would be directly contrary to that in the last case.

When the sides of a ship fall out at the same angle of inclination both above and below the water's surface, or fall in at the same angle of inclination both above and below the water's surface, the effect is the same as in the first case, (Fig. 33.)

From the preceding remarks, and from the inspection of Fig. 32, it appears, that when the centre of gravity is above the water-line, as at G, the ship will rise or fall a distance dependant on the values of the expression, G g − G F, G g − G Q, and G g $\backsim$ G N; when the centre of gravity is in the water-line, as at g, the ship will rise or fall a distance dependant on the values of H Q and Q F; and when the centre of gravity is below the water-line, as at γ, the ship will rise or fall a distance dependant on the values of the expressions, $\gamma g - \gamma h$, $\gamma g - \gamma q$, and $\gamma g \backsim \gamma f$.

To find a general expression for the rising or falling of a ship, under all circumstances, let the volume immersed (Fig. 32) contained between the planes passing through B g and E g, and the part of the ship's side, B E, be represented by a, and the volume emerged, contained between the planes passing through D g and A g, and the part of the ship's side, A D, be represented by b; and let G g or γg, the distance between the centre of gravity of the ship and the intersection of the planes D E and A B, be represented by c.

Then G g − G F $= c -$ (c. cos. $\angle$ incl. − F Q.)
and to find the value of F Q, let the areas of the horizontal

planes, when the ship is inclined, passing through O P and D E be determined, and let the mean of these areas $= d$;

$$\text{then, } a \backsim b = d.\ \text{F Q nearly,}$$

$$\text{and F Q} = \frac{a \backsim b}{d}$$

$$\text{and G}g - \text{G F} = c - \left(c.\ \cos.\ \angle\ \text{incl.} - \frac{a \backsim b}{d}\right)$$

By changing the signs of this expression according to the circumstances of the case,

$$c \backsim (c.\ \cos.\ \angle\ \text{incl.} \pm \frac{a \backsim b}{d})$$

is a general expression for the rising or falling of a ship, dependant on the form of a ship within the limits of the immersion and emersion, and the situation of the centre of gravity of the ship; in which the values of all the terms may be determined by calculation for any given design.

M.

Art. XLIV.—*Subjects proposed for the consideration of Correspondents.*

(*To the Editor of Papers on Naval Architecture.*)

Sir,—Considering that many of your readers may possess valuable information on various subjects connected with Naval Architecture, but who do not, for different reasons, wish to venture on separate disquisitions on these subjects, I beg to recommend to you, that subjects should be occasionally proposed in your Numbers, for the consideration of your readers, who may thereby be induced to send you their observations for insertion in your valuable Work; which, although they may not be in all cases sufficiently long to offer as separate papers *without previous invitation,* may be extremely useful in contributing to the general stock of knowledge, and to the improvement of this very important science.

I beg to propose the following subjects for this purpose,—or, at least, such of them as you may deem proper, for insertion in your next Number.—I am, Sir,

Your obedient Servant,

N.

Portsmouth Dock-Yard, May 10, 1827.

1. What is the best form for rudders of ships?

2. Is it desirable that ships should swim on an even keel, or with a greater draught of water abaft than forward?—Giving reasons for the answer.

3. What is the best method of determining the position of the masts of ships?

4. What is the best method of fastening the plank of ships' bottoms?

5. Can any alteration be advantageously made in the present method of framing the lower timbers of East Indiamen?

6. What are the principal defects complained of by Naval Officers in the different classes of our ships of war?

7. What observations made on the action of ships at sea by Naval Officers should be registered for the use of constructors?

8. What are the best methods of rendering steam vessels applicable for purposes of warfare?

9. Is the present substitution of iron for timber in the different parts of ships, in all cases advantageous, and what further substitution of iron for timber may be beneficially made?

10. Are any alterations likely to take place in naval warfare by the late French invention of bomb-cannon?

11. What is the best method of propelling ships of war in calms?

12. What is the best method of securing the ends of beams to ships' sides?

The Editors are much obliged for this communication, which they consider to be the principal object of this work, and will be most happy in receiving observations on any of the preceding questions, or on *any* other subject connected with Naval Science. They do not expect any great advancement in this most extensive subject from their own labours, but from the collection of the observations of experienced Naval Officers, scientific and practical Ship-builders, and all interested in Naval affairs, they anticipate eventually very important improvements in this science.

ART. XLV.—*Principal Dimensions, &c., of his Majesty's Ships composing the Experimental Squadron under the command of Rear-Admiral Sir Thomas Hardy, Bart. K.C.B. &c.*

	CHALLENGER, 28 guns, constructed by Captain Hayes, Royal Navy.		TYNE, 28 Guns, constructed by Sir Robt. Seppings, Surveyor of the Navy.		SAPPHIRE, 28 Guns, constructed by Professor Inman, of the Royal Naval College.		WOLF, 18 Guns, constructed by Captain Hayes, Royal Navy.		ACORN and SATELLITE, 18 guns, constructed by Sir Robt. Seppings, Surveyor of the Navy.		COLUMBINE, 18 Guns, constructed by Capt. Symonds, Royal Navy.	
	Feet.	Inch.	Feet.	Inch.	Feet.	Inch.	Feet.	Inch.	Feet.	Inch.	Feet.	Inch.
Length on the lower Deck	125	$7\frac{1}{2}$	125	0	119	0	113	$4\frac{1}{2}$	112	0	105	$0\frac{1}{2}$
Breadth Extreme	32	$8\frac{1}{2}$	32	$6\frac{1}{2}$	33	8	30	$6\frac{1}{4}$	30	6	33	$2\frac{1}{4}$
Length of the Keel for Tonnage....	105	$11\frac{1}{2}$	106	$7\frac{1}{8}$	100	$7\frac{1}{2}$	91	$8\frac{1}{4}$	92	$1\frac{3}{8}$	84	$0\frac{1}{8}$
Depth in Hold	9	$3\frac{1}{4}$	9	9	8	0	7	$10\frac{3}{4}$	* 13	10	7	11
Burthen in Tons	$602\frac{88}{94}$		600		$605\frac{69}{94}$		$454\frac{84}{94}$		$455\frac{74}{94}$		$492\frac{14}{94}$	

* Measured from the Main Deck.

Art. XLVI.—*Remarks on the Resistance of Fluids, by* John Wilson, Esq., *of the Navy Office, London.*

A correct Theory of the Resistance of Fluids is of such great importance to Naval Architecture, that an attempt to improve the common theory, which in its present state is inapplicable to any practical purpose, will, it is hoped, be received, by the readers of the Papers connected with Naval science, with some degree of indulgence.

In the theory laid down by Sir Isaac Newton, which is founded on impulse alone, certain propositions have been deduced which are found to agree but ill with experiments; this is owing to the necessity that there was, in order to arrive at mathematical demonstration, of conceiving an hypothetical fluid whose particles should be so far apart, that, after impinging on the obstructing body, they could rebound without interfering with the other particles which were approaching the same body. But such a fluid is so very different from any we meet with in nature, that the greatest part of the resistance of fluids arises from the particles being so close together that their only way of escape (after impulse) is over the border of the obstructing body. The resistance, therefore, divides itself,—First, into that arising from impulse, which is in proportion to the surface; and, secondly, that which is produced by the difficulty presented by the border of the solid body, to the escape of the particles of the fluid after impulse. To find out what portion of the total resistance is due to this difficulty, it will be necessary to consider how it would be affected on two square surfaces of different dimensions. In order to have distinct ideas on the subject, let us suppose the fluid to be air, and the obstructing bodies to be square planes, and let the side of one square plane be twice the length of that of the other, the latter would have four times the number of particles of air to impinge upon it, and then escape over the border, which the former would have, but having only twice the length of border, it is evident they must move, in order to escape in the same time, with twice the velocity; this will give double resistance to each particle, and as there are four times the number of particles, the resistance

due to the difficulty of the escape of the air over the edges of the plane will be eight times greater with the larger plane than with the smaller one: that is, it will be as the cubes of the sides of the planes.

To prove the correctness of this view of the subject, we will apply this improved theory to ascertain the force of the wind on the sails of the largest and smallest classes of vessels, where the stability will give the accurate measure of the force, and the difference in the size of the sails, as we take the cubes of their sides into consideration, will discover at once any discrepancy in the calculations. Before we can do this, it will be necessary to find out what portion of the total resistance is due to the *impulse* of the particles of the fluid, which is as the *square*, and what portion is due to the difficulty of the *escape* of the fluid, which is as the *cube* of the side of the plane. It will also be necessary to ascertain the modification of the force of the fluid when it strikes the plane obliquely.

The Chevalier Borda found that the resistances, with the same velocity, to square planes whose sides were 3, 4, 6, and 9 French inches, were 9.0, 17.535, 42.75, and 104.737 respectively; now if we multiply the squares of the sides of the planes by 1.064 for the resistance due to the impulse, and the cubes of their sides by ,0196 for the resistance due to the escape of the fluid, we shall produce the following numbers :—

Sides of the Planes.	Square of the sides multiplied by 1,064.	Cube of the sides multiplied by ,0196.	Total Resistances.
3	9,5	,1	9,6
4	17,0	1,2	18,2
6	38,3	4,2	42,5
9	86,1	14,3	100,4
11.257	134,8	27,9	162,7

The numbers in the last line are added for a plane of an English foot square. The resistances in the last column approximate sufficiently to those given by the Chevalier Borda,

which must have been derived partly from calculation, as it is idle to suppose he could measure them so accurately as to the thousandth part of an ounce, which his numbers would indicate. As it will be more convenient, in all our calculations, to take the English foot for the unit, and the avoirdupois pound for the measure of force, and as we are limiting our views, in the first instance, to the sails of a ship as acted upon by the wind, it will be necessary to find out what is the force of the wind in some particular case. That very excellent experimentalist, the late Colonel Beaufoy, ascertained that when the wind blows at the rate of 20,29 feet per second, it exerts a force on a square plane directly opposed to its motion, whose area is one foot, of ,85 lb. avoirdupois; and, what is of great importance in our investigation, a ship can in this case barely carry her top-gallant sails. The number, deduced from this experiment, for multiplying the square of the length of the side of the plane in *feet* will be ,7, and that for multiplying the cube will be ,3, the sum of those products multiplied by ,85 will give the force of the wind on a plane placed at right angles to its course, in pounds avoirdupois: this is the direct resistance.

To find the oblique resistance, we will, in the first place, consider what it would be on a pyramid, whose base is a square plane, the apex being placed so that the four sides shall present planes of equal obliquity to the wind. In this case the resistance caused by the difficulty of the fluid in passing the border, which we shall call the *removing resistance*, will be the same as in a plane of the same dimensions as the base of the pyramid, and placed at right angles to the direction of the wind: because it must either pass the border, in both cases, with equal velocity; or, what will amount to the same thing, if the length of the pyramid be increased, by which the velocity will be decreased, and the quantity of fluid to be removed to the border at the same time will be proportionably increased, the same momentum will be given.

The resistance which a pyramid, with its apex foremost, sustains is not applicable to the sails of ships, but as the same reasoning applies to cones and solids formed by the revolution of curves, of any description, round their axes, its importance in ascertaining the resistance on the prow of a ship is manifest.

In planes placed obliquely to the wind, the *removing resistance* will be the same as on a square plane placed so as to receive the direct force of the wind, provided the oblique plane occupies the same sectional area of the stream as the square plane: for, although the quantity of fluid to be removed at one time be increased as the obliquity of the plane increases, the velocity diminishes in exactly the same proportion, therefore the momentum is the same.

The correctness of what has just been observed, is confirmed by experiments made by Colonel Beaufoy, and detailed in the Annals of Philosophy, vol. vi. page 277. A wedge with its edge foremost, and whose base was one foot square, the sides being inclined 45° to the direction of its motion, and moving with a velocity of 20 feet in a second, sustained a resistance of 8,207 ounces avoirdupois; and a plane of the same size as the base of the wedge met with a direct resistance of 13,567 ounces: this will give us for the impulsive resistance 9,49, and for the removing resistance 4,07. Now, if we reduce the impulsive resistance on the sides of the wedge in the proportion laid down by the writers on the theory of fluids, namely, as the square of the radius to the square of the sine of the angle of incidence, it will be 4,74, which, added to the same removing resistance which the square plane had, 4,07, gives 8,81 for the resistance of the wedge, as deduced from the theory as improved. The difference between this sum and that found by experiment is occasioned partly by the unavoidable inaccuracy of all experiments on this subject, and partly by the minus pressure, as the air passing along the sides of the wedge will more easily fill the vacuity at the back of the wedge than that at the front of the plane can pass over to fill the vacuity at the back of the plane.

We will now enumerate the rules for the impulsive and removing resistances which are applicable to the case we have in view, namely, the force of the wind on the sails of a ship, as opposed to her stability.

First,—The direct resistance, in pounds avoirdupois, arising from the impulse of the wind on a square plane, when ships can barely carry their top-gallant sails, is as the square of the side of the plane in feet, multiplied by ,7, and then by ,85

added to the resistance we have been investigating, and which is, as the cube of the side of the plane multiplied by ,3 times ,85.

Secondly,—The direct impulsive resistance, found by the preceding rule, reduced in the proportion as the square of radius to the square of the sine of the angle of incidence which the wind makes with the plane, will give the absolute oblique impulsive resistance: to this must be added the removing resistance, found by taking the area of the section of the stream of wind which the plane intercepts, then raising it to the $\frac{3}{2}$ power, and multiplying it by ,8 times ,85; this will give the removing resistance in the direction of the wind, which must be reduced to the direction perpendicular to the surface of the plane, in the proportion of radius to the sine of the angle of bracing. To apply this rule to the sails of ships, the sum of the impulsive and removing resistances must be again reduced in the proportion, as the radius is to the sine of the angle which the yards make to the athwartship line of the ship.

In the following Tables each sail is supposed to be a square plane, a form to which they all (except the jib) approximate very nearly.

We shall now apply these rules to ascertain the force of the wind on the sails to incline a first-rate ship of war of 120 guns, and 2601 tons, assuming that the sails are braced to an angle of 30° to the direction of the wind, and of 52° to the athwartship line of the ship, and also supposing the force of the wind such that a ship can but barely carry her top-gallant sails.

Names of the Sails.	Areas.	Effort of the Sails. Impulsive Resistance.	Removing Resistance.	Total.	Height from the Centre of Effort of the Sails to that of the Water.	Moment.
	Feet.	Lbs.	Lbs.	Lbs.	Feet.	
Fore course	3420	509	8262	8771	67	585657
Fore-topsail	4470	666	12342	13008	116	1508928
Fore-top-gallant sail ..	1620	241	2691	2932	165	483780
Main course	4950	737	14391	15128	68	1028704
Main-topsail	5630	838	15603	16441	125	2055125
Main-top-gallant sail .	2020	300	3745	4045	183	740235
Mizen course	1950	290	3559	3849	75	288675
Mizen topsail	2490	371	5127	5498	110	604780
Mizen-top-gallant sail.	930	138	1169	1307	148	193436
Jib.	2090	311	3949	4260	91	387660
Total....	29570					7876980

This moment reduced in the proportion of radius to the sine of 52°, gives 6207060; which, divided by 10467520, the weight of the ship in pounds, the quotient is ,593. Then, as 4,75, the height of the metacentre above the centre of gravity of the ship, is to ,593, so is radius to the sine of 7° 10′, the inclination of the ship.

We will now make the calculations for a vessel of forty tons burthen, and with similar conditions as for the first-rate.

Names of the Sails.	Areas.	EFFORT OF THE SAILS. Impulsive Resistance.	Removing Resistance.	Total Resistance.	Height of the centre of effort of the sails from that of the water.	Moment.
	Feet.	Lbs.	Lbs.	Lbs.	Feet.	
Mainsail . . .	1000	149	1304	1453	25.7	37342
Main-top-sail . .	468	69	411	480	53.	25440
Foresail	205	30	120	150	20.5	3075
Jib	310	46	224	270	21.	5670
Total . .	1983					71528

This moment reduced as before, gives 56364, and, divided by 89600, the weight of the vessel in pounds, gives ,629; the metacentre in this vessel is 3,53 above the centre[1] of gravity, therefore as 3,53 is to ,629, so is radius to the sine of 10° 13′, the inclination of the vessel.

These results, which are exceedingly near the fact, are sufficient to establish the value of the proposed amendment of the common theory; but as nothing can better prove the degree of goodness of a proposition than contrasting it with that which it is intended to substitute, the two next Tables are added to show what the results would be with the same vessels under similar circumstances, but calculated on the common theory of the resistance of fluids, and by the following proposition, usually demonstrated by the writers on that theory, viz.—"The direct impulse on any surface is to the effective oblique impulse on the same surface, as the cube of radius to the solid which has for its base the square of the sine of incidence, and the sine of obliquity for its height."

[1] The writer of this Paper has calculated the positions of the centres of gravity of the two ships mentioned, and of several others, accounts of which will be given in the future Numbers of this work.

FIRST-RATE, OF 120 GUNS, AND 2601 TONS.					
Names of Sails.	Areas.	Direct Resistance	Effective Oblique Resistance	Height of the centre of effort of the Sails from that of the Water.	Moment.
	Feet.	Lbs.	Lbs.	Feet.	
Fore course	3420	2915	578	67	38726
Fore-top-sail	4470	3790	750	116	87000
Fore-top-gallant sail . .	1620	1340	265	165	43725
Main course	4950	4280	830	68	56440
Main-topsail	5630	4810	950	125	118750
Main-top-gallant sail . .	2020	1720	340	183	62220
Mizen course	1950	1660	325	75	24375
Mizen-top-sail	2490	2120	420	110	46200
Mizen-top-gallant sail .	930	790	155	148	22940
Jib	2090	1775	350	91	31850
Total	29570				512226

This momentum divided by the weight of the ship gives ,0489; then as the height of the metacentre above the centre of gravity of the ship, which is 4,75, is to ,0489, so is radius to the sine of 0° 35′, the inclination of the ship. This result is not one-twelfth of what actually takes place in first-rates under the circumstances supposed.

VESSEL OF FORTY TONS BURTHEN.					
Names of Sails.	Areas.	Direct Resistance	Effective oblique Resistance	Height of the Centre of Effort of the Sails from that of the Water.	Moment.
	Feet.	Lbs.	Lbs.	Feet.	
Mainsail	1000	850	167	25.7	4291
Main-topsail	468	397	78	53.	4134
Foresail	205	174	34	20.5	697
Jib	310	264	52	21.	1092
Total . . .	1983				10214

As 3,53 is to $\frac{10214}{89680}$, so is radius to the sine of $1^{\circ}\,51'$, the inclination of the vessel. This result is only one-fifth of what the vessel heels under the circumstances supposed, while that for the first-rate is but one-twelfth, which shows that the error is not in the quantity assigned to each foot (.85 lbs.), but in the theory itself.

It now remains to apply this theory to the resistance of water to the motion of solid bodies moving in it, where it will be necessary to take into the calculation the minus pressure, on account of the various forms which are given to the after end of such bodies, which greatly modify the resistance, and also the friction; two circumstances, the first of which does not apply, and the second is of small account in the sails of ships; and in doing this most of the anomalies observed in the experiments of different authors, particularly Romme, will be completely corrected. But as this article is already extended beyond the limits assigned it, the consideration of the subject must be postponed to a future Number.

From what has already been investigated, it may fairly be concluded that this theory will give correct results for air in

all cases, as it has been shown so to do on surfaces from one-sixteenth of a foot to 5630 feet, and various intermediate sizes; while the common theory gives such erroneous results, that it is utterly useless.

ART. XLVII.—*The Dimensions and calculated Elements of some of the Frigates of the smallest Classes, with some Remarks on their Design. By* JOHN FINCHAM, ESQ., *Superintendent of the School of Naval Architecture.*

THE advantage of Tables of the calculated elements of our ships of war has been for some time considered of the first importance to the advancement of Naval Architecture; and however difficult the task may be to carry it to its full extent of usefulness, still its advantages are too evident to admit of its not being ultimately attained. Though the advances may be slow, yet the increasing energy, and the present excitement to the pursuit of Naval Architecture, must ensure its accomplishment, from its being the only sure and certain means of guiding constructors in the design of good ships; since all modes that are not grounded on correct quantities must be uncertain as to their accomplishment. It is with this view that this attempt at an analysis of our small class of frigates has been commenced, as making a small advancement towards the attainment of this important object.

The principal defect in the following Tables, is the necessity of assuming the situation of the centre of gravity, instead of having it correctly determined by experiment and calculation; a circumstance absolutely necessary to be known in all classes of ships, in order to give their correct measure of stability, as strongly insisted on in a former Article[1] of this Work. It is most earnestly to be hoped that before long this important element will be found in all classes of his Majesty's ships, under different circumstances.

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[1] Art. III.

Dimensions and calculated Elements of the small class of Frigates.

	SHIPS OF 28 GUNS.					SHIPS OF 24 GUNS.
	When Built.					
	1756	1778	1827	1825	1823	1781
	No.	No.	No.	No.	No.	No.
Burthen in tons (builder's tonnage)	587	603	605	520	500	521
	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
Length on the range of upper deck, from the aft-part of the rabbet of the stem to the fore-part of the rabbet of the post	120.3	122.0	122.2	117.7	115.3	115.5
Length of the water-line from the fore-part of the stem to the after-part of the post	120.	122.5	121.7	117.	115.9	116.4
Breadth extreme to the thickness of the plank of the bottom	33.6	33.5	33.9	31.83	31.5	32.25
Breadth at the water-line to the outside of the planking	33.8	33.7	33.9	32.2	31.8	32.5
Breadth of the wing-transom	21.8	19.6	21.0	18.5	[illegible]	18.8
Height of wing-transom above the water at the middle	5.[illegible]	5.5	3.3	2.9	2.7	4.2
Draught of water } Afore	15.0	15.2	15.0	15.5	15.2	14.5
Draught of water } Abaft	16.25	15.4	15.8	15.66	15.5	15.5
Depth of keel and false keel below the lower part of rabbet	1.2	1.25	1.5	1.3	1.3	1.2
Height of ports amidships	5.76	6.5	5.1	5.5	5.3	6.0
Greatest transverse section before the centre of gravity of displacement	8.25	9.5	*	5.0	3.7	9.5
	Pr. No.	Pr. No.	Pr. No.	Pr. No.	Pr. No.	Pr. No.
Ordnance on the upper deck, guns	9—24	9—24				9—20
.... carronades			32—20	32—20	32—20	
Ordnance on the quarter-deck, guns	6—4	6—4				
.... swivels	½—6	½—4				4—2
.... carronades			18—6	18—6	18—6	

* For the Elements of the 28-gun ship, built in 1827, see Art. XXXII.

	SHIPS OF 28 GUNS. When built.					SHIPS OF 24 GUNS.
	1756	1778	1827	1825	1823	1781
	Pr. No.	Pr. No.	Pr. No.	Pr. No.	Pr. No.	Pr. No.
Ordnance on the forecastle, guns		6—2	9—2	9—2	9—2	4—2
swivels	½—2	½—2				
Area of the greatest transverse section, in square feet	323	366		312	333	349
Area of load-water section, in square feet	3295	3381		3253	3230	3119
Area of the vertical longitudinal section, in square feet	1884	1851	1871	1793	1751	1772
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
Light displacement	407	421	432	371	387	351
Quantity of ballast	160	160	58	63	80	145
Quantity of water	58	58	68	54	50	48
Additional weight by carrying the water in tanks			6	4	3.7	
Additional weight by carrying chain cables			7.5	7	7	
Weight of ordnance	38	38	32	32	32	31
Weight of provisions, masts, rigging, sails, stores, &c.	185	199	269	216	223	186
Total displacement in tons	848	869	872	752	782	761
Total displacement in cubic feet	29680	30415	30520	26320	27370	26635
Displacement before the centre of gravity, in cubic feet	15004	15274		13472	13682	14104
Displacement before the centre of gravity, in tons	428	436		385	390.8	403
Displacement abaft the centre of gravity, in cubic feet	14702	15164		12848	13688	13758
Displacement abaft the centre of gravity, in tons	420	433		367	391.2	393.
Solid immersed to an inclination of 10°, in cubic feet	2190	2149		2121	2026	1940
Depth of centre of gravity of displacement below the load-water line, in feet	5.52	5.4		4.83	4.96	5.39
Depth of centre of gravity of the greatest transverse section below the load-water line, in feet	6.01	5.83		5.2	5.54	5.99

Dimensions and calculated Elements of the small class of Frigates.

	SHIPS OF 28 GUNS.					SHIPS OF 24 GUNS.
	When built.					
	1756	1778	1827	1825	1823	1781
	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
Distance of centre of gravity of displacement from the middle of the length at the water-line between the fore-part of the stem and the aft-part of the stern-post	3.0	3.1	[For a 28 gun ship, see Art. 32.]	1.8	1.5	2.3
	abaft.	abaft.		abaft.	abaft.	abaft.
Distance of the centre of gravity of the load-water line from the centre of gravity of displacement	2.5	1.55		.65	2.3	1.35
Distance of the centre of gravity of the solid that is before the centre of gravity of displacement before the said centre	21.35	22.9		23.3	22.57	21.6
Distance of the centre of gravity of the solid that is abaft the centre of gravity of displacement abaft the said centre	21.76	23.1		24.5	22.55	22.12
	abaft.	abaft.		before.	abaft.	abaft.
Distance of the centre of gravity of the solid immersed to an inclination of 10° from the centre of gravity of displacement	.17	.15		.121	1.4	1.0
Ditto of the part emerged by an inclination of 10°	1.2	.19		.151	1.6	1.46
Distance of the centre of gravity of the vertical longitudinal section from the centre of gravity of displacement	6.	5.3		4.4	4.5	4.9
Height of metacentre	3.15	3.31		4.15	3.69	2.68
Measure of stability at an inclination of 10°, calculated agreeably to Atwood's method [See Phil. Trans. of Royal Society for 1798.]	.155	.153		.175	.163	.44
Moment of stability at an inclination of 10°, = displacement multiplied by the measure above	473	467		568	494	356
Area of sails, in square feet	12974	12974	13589	10166	10166	10792
Moment of sails	753537	758726	776927	504750	509344	575112
Centre of effort before the centre of gravity of displacement, in feet		2.8	3.9	5.1	5.3	5.2
Height of the centre of effort of the sails above the load-water line, in feet		58.4	57.8	49.6	50.1	53.2

	SHIPS OF 28 GUNS.					SHIPS OF 24 GUNS.
	When built.					
	1756	1778	1827	1825	1823	1781
	Feet	Feet.	Feet.	Feet.	Feet.	Feet.
Moment of the effort of sails abaft the centre of gravity of displacement		206352	221313	before. 148828		155828
Moment of the effort of sails before the centre of gravity of displacement		242654	274470	200775		211965
Area of sails abaft the centre of gravity of displacement, in square feet		8128	8246	6215		6583
Area of sails before the centre of gravity of displacement, in square feet	4844	4844	5352	3949		4209
Ballast, in terms of the displacement	,188	,184	,066	,083	,102	,19
Displacement in proportion of a circumscribed rectangular parallelopiped; contained by the length on the water-line (from the fore-side of the rabbet of the stem to the after-part of the rabbet of the post), breadth at the water-line, and mean draught of water to the lower edge of the rabbet of the keel	,53	,53	,53	,5	,48	,49
Area of load-water section in proportion to a circumscribed rectangle contained by the length and breadth on the water-line	,82	,83	,9	,87	,88	,83
Area of midship section in proportion to a circumscribed rectangle contained by the breadth at the water-line, and depth from the water-line to the lower side of the rabbet of the keel	,74	,77	,68	,69	,7	,71
Comparative moment of sails in relation to the stability	1584	1624	918	888	1021	1634

Proportions of Masts, Yards, &c., in Terms of known Quantities.

SPECIES OF MASTS AND GEAR.	KNOWN QUANTITIES.	PROPORTIONS.					
		28 Guns, built 1756.	28 Guns, built 1778.	28 Guns, built 1827.	28 Guns, built 1825.	28 Guns, built 1823.	24 Guns, built 1781
Main-mast	Breadth	2,41	2,41	2,33	2,23		2,32
Main-top-mast	Breadth	1,51	1,51	1,44	1,357		1,39
Main-top gallant-mast	Breadth	,72	,72	,71	,68		,69
Fore-mast	Main-mast	,885	,883	,89	,91		,88
Fore-top-mast	Main-top-mast	,87	,87	,89	,88		,88
Fore-top-gallant-mast	Main-top-gallant-mast	,88	,88	,91	,88		,88
Mizen-mast	Main-mast	,74	,74	,77	,76		,853
Mizen-top-mast	Main-top-mast	,75	,75	,73	,752		,73
Mizen-top-gallant-mast	Main-top-gallant-mast	,758	,758	,75	,755		,75
Bowsprit	Fore-mast	,7	,7	,68	,69		,69
Jib-boom	Bowsprit	,699	,699	,71	,738		,76
Main-yard	Length	,59	,59	,58	,553		,574
Main-top-sail-yard	Main-yard	,74	,74	,763	,74		,747
Main-top-gallant-yard	Main-top-sail-yard	,606	,606	,639	,609		,637
Fore-yard	Main-yard	,87	,87	,89	,873		,88
Fore-top-sail yard	Main-top-sail-yard	,87	,87	,89	,88		,88
Fore-top-gallant-yard	Main-top-gallant-yard	,88	,88	,89	,88		,88
Cross-jack-yard	Main-top-sail-yard	,87	,87	,1	,1		,1
Mizen-top-sail-yard	Main-top-sail-yard	,665	,665	,654	,665		,66
Mizen-top-gallant-yard	Main-top-gallant-yard	,75	,75	,71	,753		,82
Driver Boom	Length	,41	,41	,39	,395		,39
Gaff	Driver Boom	,73	,73	,72	,724		,778
		Inches.	Inches.	Inches.	Inches.		Inches.
Rake of Main-mast	In 12 feet	4½	4½	5½	6		4
Rake of Fore-mast	Ditto	0	1	1¼	2		0
Rake of Mizen-mast	Ditto	7½	7½	11	10		6
		Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
Stive of Bowsprit	Ditto	6,3	6,4	4,6	5,0	5,3	6,0
Fore-mast before middle of the length of the water-line	Length of water-line	,383	,375	,364	,377	,37	,376
Main-mast abaft	Ditto ditto	,0698	,062	,073	,066	,061	,065
Mizen-mast ditto	Ditto ditto	,362	,349	,35	,34	,342	,348

Sails of Ships of 28 *Guns, built in* 1778.

SPECIES OF SAILS.	In relation to Loadwater Section.			In relation to the middle of the Length of the Loadwater Section.		
	Areas.	Heights of centres of gravity.	Moments.	Distance from Middle.	Moments before.	Moments abaft.
Jib	934	55,1	51477	80,6	75301	
Fore-course	1652	33,4	55183	46,2	76331	
Fore-top-sail	1728	67,5	116676	46,8	80895	
Fore-top-gallant-sail	530	98,6	52258	47,4	25143	
Main-course	2406	34,3	82520	7,2		17322
Main-top-sail	2276	74,4	169344	6,84		15569
Main-top-gallant-sail	719	110,1	79149	6,5		4668
Mizen-top-sail	992	65,6	65091	41,3		41476
Miz.-top-gallant-sail	383	91,	34913	41,8		15845
Driver	1352	39,2	52109	63,8		86276
	12974		758726		257670	181156

Height of centre of Effort $\frac{758726}{12974} = 58.4$ feet.

Distance of the centre of Effort before the middle of the Water-line from the fore-part of Stem to after-part of Post. $\Big\}$ $\frac{257670 - 181156}{12974} = 5,9$ feet.

Note.—For 28-gun Ships, built in 1827, see ART. XXXII.—The Sails for the 28-gun Ships built in 1756 could not be obtained by the writer of this Paper.

Sails of Ships of 28 Guns, built in 1825.

SPECIES OF SAILS.	In relation to Loadwater Section. Areas.	Height of centres of gravity.	Moments.	In relation to the middle of the Length of the Loadwater Section. Distance from Middle.	Moments before.	Moments abaft.
Jib................	848	43,5	36888	79,3	67246	
Fore-course.........	1375	28,0	38499	45,5	62561	
Fore-top-sail	1310	58,7	76885	45,3	59333	
Fore-top-gallant-sail	416	86,0	35819	45,0	18743	
Main-course	1836	29,5	54161	6,9		12668
Main-top-sail	1720	64,0	110123	7,65		13163
Main-top-gallant-sail	559	94,6	52965	8,15		4553
Mizen-top-sail	764	55,0	42037	42,0		32101
Miz.-top-gallant-sail	286	7,7	22064	43,		12321
Driver	1050	33,6	35305	59,		62835
	10166		504756		207883	137641

Height of centre of Effort $\frac{504756}{10166} = 49.6$ feet.

Centre of Effort before the middle of the Water-line taken from the fore-part of the Stem to after-part of Stern-post. $\frac{207883 - 137641}{10166} = 6,9$ feet.

Note.—The 28-gun Ships, built in 1823, have the same Sails; but the centre of Effort, from the position of the Masts, is carried ,2 foot further forward.

Sails of Ships of 24 *Guns, built in* 1781.

SPECIES OF SAILS.	In relation to Loadwater Section.			In relation to the middle of the Length of the Loadwater Section.		
	Areas.	Heights of centres of gravity.	Moments.	Distance from Middle.	Moments before.	Moments abaft.
Jib...............	944	48,4	45701	77,4	73084	
Fore-course	1323	29,6	39162	45,2	59801	
Fore-top-sail	1482	60,2	89326	45,6	67584	
Fore-top-gallant-sail	460	89,4	41155	46,0	21176	
Main-course	1912	31,4	60035	7,		13384
Main-top-sail	1940	67,0	130014	7,3		14166
Main-top-gallant-sail	589	100,0	58900	7,36		4333
Mizen-top-sail	804	61,	49041	41,75		33565
Miz.-top-gallant-sail	306	83,8	25688	42,33		12976
Driver	1032	35,0	36139	60,3		62264
	11792		575161		221645	140688

Height of centre of Effort $\frac{575161}{10792} = 53,2$ feet.

Distance of the centre of Effort before the middle of the Water-line from the fore-part of the Stern to the after-part of the Stern-post .... $\Big\} \frac{221645 - 140688}{10792} = 7,5$ feet.

With such calculated elements as are given in these Tables, and a clear and correct statement of facts connected with each class of ships, and a knowledge of the principles upon which they depend, a constructor cannot fail, to a certain extent, of being successful in his design. While, from not having a correct statement of the stowage[1] of our ships of war, and from many of the laws that govern their formation not being clearly developed, he may not arrive at once at that perfection of form which is desirable to be attained; still it may be affirmed, that, with a steady and persevering combination of experience, obtained by these elements and observations, with scientific investigation, he will be certain of advancing towards it.

To obtain all the information that an extended comparison of our ships of war can give, we must not confine ourselves merely to those ships that have been lately built; but our researches must be extended to old ships, since we have no good reason to conclude that the formation of all classes of our ships of war has been improving; in some cases we have, indeed, evidence of the contrary, from the observation of some of our most experienced officers; and from the circumstance that the formation of our ships has been too frequently governed more by speculative opinions, as to what is the best form, dimensions, &c., than by a comparison of effects produced by bodies differently adjusted, as shown by a combination of their different elements.

In forming an analysis of ships, it will be found as useful to have the position, area, and moment of sails, as the elements of the construction of the body; for the proper form and adjustment of the body is not more necessary to the properties of the ship, than a proper disposition and power of sail.

In determining the proper disposition of sail by a comparison with other ships which have their sails properly balanced, as to the relative position of the point of sail and place of the masts, in connexion with those elements that are known most to effect the direct and lateral resistances, the danger of falling into

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[1] Rear-Admiral Sir Thomas Hardy has directed an exact account to be taken of the weights put on board, and a correct statement of the stowage to be given of all the experimental ships; this method, if extended to all classes of ships, must ultimately be of essential benefit to the service.

any considerable error will be prevented; and by experience thus obtained, and by a comparison of the moment of sail before and abaft the centre of gravity, we may know, to a certain degree, that the ship will carry her helm properly and work with certainty.

It is not sufficient to depend only on the position of the centre of effort of the sails, without regarding the moment of sail before and abaft the centre of gravity; the ship may be properly balanced on a wind, while the moments before and abaft may not be in correct relation to each other, so as to produce a proper influence on the ship in working. When the ship is in stays, it requires a certain and reciprocal effect to be produced by the sails forward and aft; for if the moment of sail be too powerful forward, and the sails be not worked quickly, stern-way is the consequence, and the mean resultant of the water will pass to the lee-quarter, and the ship will fall off too much before she has recovered her way through the water, and considerable time will be lost before she can be brought by the wind. If, on the contrary, the after-moment be too powerful, the ship may come to, before head-way is obtained and the head-sails are brought to act. These effects produced in working the ship may be prevented, to a certain extent, when there is not too great an influence produced by the excess of either of the moments, by an attention to the trim of the ship and bracing the yards. This, however, must not be depended on, since to produce this trim the ship may be rendered uneasy, and made to plunge too deep; but we must attain, as near as possible, the correct proportions, by an attentive comparison of the fore and after moments of ships that work well, with other elements in relation to which the placing of the sails depends.

To discover the correct relation which the fore and after moments should bear to each other, can only be done by examining their relation for a number of ships. In a ship that had a strong tendency to come to in-stays, the fore moment, from the middle of the length on the water-line, was found to the after moment as 1 : ,84; while in a ship that was found to fall off in-stays, the fore moment was to the after moment as 1 : ,66.

The comparative moments of several other ships that were found to work well, according to the reports given by experienced officers on board them, varied from 1 : ,72 to 1 : ,77. It would appear, therefore, according to the experience we have from good ships, that the relation of the moments should be somewhere between these two limits; and having determined this, which may be done with more certainty by examining the moments of a greater number of ships, any little disposition to come to or fall off may always be corrected by an attention to the trim, and that without making the ship uneasy.

To determine the proper power of sail is less difficult, while it is of no less importance; for to give to each class of ships the proper power of sail, it only becomes necessary to have the moment of sail in some terms of the stability, so that the ship may not exceed a determined inclination, under certain circumstances. When these are defined we have only to bring the moment of sail to the given terms of the stability, as calculated for the determined inclinations, or to estimate the moment of stability at the inclination under the given circumstance, and make the moment of the power of the wind on the sails equal to it.

By comparing the moment of sail with the stability, some fixed terms may be obtained, whereby, under similar circumstances, an equal inclination may be produced in the same class of ships. The manner in which one ship will carry sail when compared with another of the same class, shows the necessity that some relative moment should be given, or some inclination defined under certain circumstances, that the best performance may be obtained by a sufficient power of sail being given, while by not having too much inclination the lee-guns may be properly fought.

The Swedish author, Chapman, in his valuable little Treatise on the "Area of Sails," gives an example, where, in a reefed top-sail gale, which would be classed by our seamen as a moderate gale, with two reefs in the main and fore-top sail, and one in the mizen-top sail, main and fore courses, and with the staysails that are commonly set in their service, the inclination was not more than $7\frac{1}{2}$ degrees; and in another case, with a top-

sail gale, equal to our strong breeze, with men at their quarters on the lee-side, the inclination did not exceed 7 degrees. That ships should not exceed this inclination in time of action, even in a strong breeze, to allow the guns to be effective, appears most desirable; but, since the circumstances are so variable, under which ships are brought into action, from the quantity of sail that may be set, or from the different strength of wind, it would be very difficult to establish a rule on these grounds; while, if we have the stability calculated for ships of different classes, and which have been masted properly to their power, and have been found sufficiently stiff under all circumstances, we have then only to discover what power of wind would give a momentum of sail equal to their stabilities, or, what would be the same, to determine their moment of sail in terms of the stability.

The Moments of Sail and of stability in Ships which have carried their Sails well.

THREE DECK SHIPS.		TWO DECK SHIPS.		FRIGATES.		SLOOPS.		BRIGS OF 18 GUNS.		BRIGS OF 10 GUNS.	
Moment		Moment		Moment		Moment		Moment		Moment	
Of Sails.	Of Stability at 10° of Inclination	Of Sail.	Of Stability at 10° of Inclination	Of Sails.	Of Stability at 10° of Inclination	Of Sails.	Of Stability at 10° of Inclination	Of Sails.	Of Stability at 10° of Inclination	Of Sails.	Of Stability at 10° of Inclination
Square Feet.	Tons.	Square Feet.	Tons.	Square Feet.	Tons.	Square Feet.	Tons.	Square Feet.	Tons.	Square Feet.	Tons.
2632121	3452	1750165	2280	1276577	1647	554484	547	442413	409	247645	207
Moments of Sail in terms of the Stability.											
759		767		775		1013		1058		1196	

The inclination that will be produced by their moment of sails, may be found very nearly under any given circumstance by knowing the force of wind on a square foot of canvas. According to the experiments made by Lynn, Smeaton, and others, the pressure in a *strong breeze* would be about two pounds on a square foot, and this will agree very nearly with that given by Chapman, in his "Area of Sails."

The most distinguishing difference between the old 28 and 24 gun frigates, when compared with the present ships of similar classes and force, without considering the general form and adjustments of their bodies, is, that their stability was less than that of the present ships, and that it was obtained by carrying a great quantity of ballast, instead of obtaining it by form of body; and that their ports were much higher above water than the present ships of the same class.

If the centre of gravity of the ships was assumed in each case at the load-water line, the moments of stability of the old 28-gun ships would be to their moment of sails as ,0006 : 1; while the Sapphire (See Article xxxii.) would have her stability to her moment of sail as ,001 : 1; or the terms of their comparative moments of sail in relation to their stability would be, in the old ships 1584, and in the Sapphire 918. But the great quantity of ballast taken by the old ships, when compared with the present ships, considerably increased their moments of stability; for if we take, as an example, a frigate with top-gallant sails set, in a strong breeze, sailing at six points near the wind, and sails set at three points, the constant coefficient will = ,4169, a cubic foot of salt water = 64 pounds, pressure of the wind = 2 pounds, moment of sails = 1276577; the whole effort, therefore, to incline the ship will be, $\frac{,4169 \times 2}{64}$ $\times$ 1276577 = 16723 cubic feet = 478 tons = the inclining force, which is about equal to the moments of stability at an inclination of 4° of a frigate that has been taken as the example.

If we take the distance of the centre of gravity of the ballast as stowed on board the present ships, below the load-water line, at 11 feet, and the quantity 58 tons, we have 58 × 11 = 638 = moment of ballast; while the old ships have 94 tons

of shingle and 66 tons of iron ballast, the shingle at 10 feet and iron 11.5 feet below the water; we have, therefore, $94 \times 10 = 940$, and $66 \times 11.5 = 759$; $940 + 759 = 1699$ = moment of ballast in the old ships; and $1699 - 638 = 1061$ = increased moment. The displacement is 869 tons, and $\frac{1061}{869} = 1.2$, the distance by which the centre of gravity will be lowered to approach the centre of gravity of displacement.

The effect produced, therefore, in the stability will be seen by taking the common expression, $\overline{b\,a - d\,s\,V} = 467$ tons, (Atwood, Phil. Transactions, 1798,) the former moment of stability, assuming the centre of gravity, without the additional quantity of ballast, to be at the load-water line, we have $b\,a = 44853$, $d = 5.4$, and $s\,V = 5280$. By the increased ballast the centre of gravity will approach the centre of gravity of displacement by 1.2 feet; consequently we shall have it $= 5.4 - 1.2 = 4.2$, and the moment of stability $= \overline{44853 + 4.2 \times 5280} = 22677$ cubic feet $= 647$ tons, and $647 - 467 = 170$ = by which the stability is increased by carrying more ballast and less weight of stores. It is here considered that the weight of stores has not affected the centre of gravity, since, if the centre of gravity in the old ships had not been 1.2 feet lower than in the present ships, their stability would not have been sufficient to have carried the moment of sail.

The great height of the ports above water of the old ships, when compared with the present ships of similar dimensions, has not all the advantages which would at first appear by the increased height, since it not only opposes a greater resistance in going to windward, but it cannot be obtained without affecting the stability, and consequently, under sail, must bring the ports nearer the water on the lee side, which, in ships of this class, every degree of inclination would carry down the guns nearly ,3 of a foot. The inclination may be such as to render the guns useless, especially with carronades; since, when the inclination increases beyond 9°, they cannot be elevated or depressed so as to fire point-blank shot, and, consequently, both the lee and weather guns cannot be effective.

The effect which will be produced on the stability by the greater height of ports, may be seen by the following example,

taking the expression for the stability, and the quantities as before given.

To raise the ports one foot, would be to take the whole of the former topside, deck, guns, &c. &c. up one foot, and introduce one foot of topside below the gun-deck, the total weight of which, in ships of 28 guns, is about 180 tons, and the additional foot of topside for the same class of ship, about 7 tons.

The distance of the centre of gravity of additional topside will be about 4 feet from the water line, and supposing the centre of gravity to have been in the water line, we may find how much it has been raised. Let $x =$ distance raised, then $(869 + 7) \times x = 7 \times 4$, or $x = \frac{28}{876} = ,032$. The centre of gravity will be still further raised by carrying up the former topside, &c. one foot, and the additional moment being 180 tons, it will, therefore, be raised $\frac{180}{876} = ,205$; and the centre of gravity of the ship having been previously 4.2 feet above the centre of gravity of displacement, it will now become $4.2 + ,032 + ,205 = 4.437$. The centre of gravity of displacement will also be raised by the increase of displacement, in consequence of the 7 tons additional weight. The mean area of the former and new load-water section will be 3390 feet. Hence $\frac{7 \times 35}{3390} = ,072 =$ the depth of the increase of displacement, the centre of gravity of which will be ,036 above the original water line. Let x be the distance by which the centre of gravity will be raised by the increase of displacement, and we have $867 \times x = 7 \times (4.2 + ,036)$, or $x = ,034$. Consequently the distance between the centre of gravity of ship and displacement, becomes $4.437 - ,034 = 4.403$; and $b\,a - d\,s\,V$ becomes $44853 - 30660 \times 4.403 \times 1736 = 21418$ cubic feet, or the moment of stability in tons is now 612; and $647 - 612 = 35$ tons is the quantity by which the stability is reduced in consequence of raising the ports.

Numerous other comparisons might be made by reference to the Tables.

ART. XLVIII.—*Remarks on the Prospectus of a Work, intitled 'A Philosophical and Experimental Inquiry into the Laws of Resistance of Non-elastic Fluids, and Cohesion of Fibrous Solids, as far as is connected with the Theory or Practice of Naval Architecture,' &c.* By ALEX. MACKONOCHIE, Esq., *of Baypoor, near Calicut, Malabar.*

THIS Prospectus, which was published in London in 1805, takes such a comprehensive and philosophical view of Naval Architecture, that it is with deep regret we find that the work itself, which it describes at considerable length, was not given to the public. So excellent indeed are the observations in this Prospectus, which is a quarto pamphlet of not quite fifty pages, that it may be safely said, few English works on Naval Architecture contain so much valuable matter, and certainly none take so enlarged a view of the subject. Mr. Mackonochie's views were not merely those of a mathematician, chemist, or mechanist; and he had no apparent desire of theorising—no favourite hypothesis to support; but he had an earnest wish to render all knowledge, whether abstract or experimental, subservient to the improvement of Naval Architecture. Absolutely necessary as a knowledge of mathematics is for the right understanding, not only of the higher parts of the science of designing ships, but of their mechanical construction, yet it is but one of the means of investigating different branches of this subject, and thereby enlarging our acquaintance with it. It is to an enlarged experience that we must look for any great advancement in this extensive subject; to a combined acquaintance with the experience of others, rather than to the personal experience of any individual, however well qualified to enter on the investigation of any of its numerous branches, and however devotedly attached to the pursuit of its improvement. The author of this prospectus was so fully sensible of this, that he assigned as the cause of his "giving a general outline of the plan, nature, and extent" of the intended work, his hope that it would procure for the author the assistance of such men of knowledge and experience as may be pleased to favour him with their opinions; and he attributes his being

"more diffuse than the limited nature of works under the title of the present publication usually allows of, to his being, as he ought to be, exceedingly diffident of his own opinion on questions of such moment, and, therefore, before he hazards them in a more formal treatise, he wishes they should undergo a candid and liberal discussion."

It appears that, at the time of the publication of this prospectus, a considerable quantity of the matter of the proposed work, containing theoretical investigation and the results of numerous experiments, was obtained; and the writer of these remarks has been informed that numerous papers intended for the work were sent to this country after the decease of the author, which unfortunately prevented their publication. We have, however, some reason to hope, that at least some of the results of his valuable labours may, at some future time, be published.

The work was to have formed two volumes: the first more immediately referring to the science of Naval Architecture; and the second to the state of oak timber in this country, and the comparative excellency of teak timber, with its advantageous applicability to ship-building, and to the consideration of the vast resources of naval supplies which British India possesses, with the policy of particular attention being paid to their cultivation for the interests of England.

It is to the contents of the first volume that the present remarks will refer. The author proposed to consider the subject of naval architecture in three important points of view: the scientific design of the body to possess the necessary qualities of a good ship; an inquiry into the laws of cohesion of fibrous solids; and the mechanical construction of the ship, in the best disposition of the materials, so as to produce with the least quantity the greatest strength.

The work was to have commenced "with a history of the different theories that have, from time to time, been given of the resistance of fluids, the experiments and arguments used in support of them, with the objections to which they seem to be liable." Then were to follow, the results of a very extensive set of experiments made by the author, "either to discover or illustrate the laws of resistance."

The first set of experiments was divided into three classes. The first class was subdivided into eighteen orders, the angle of obliquity of the surface varying from 10° to its being perpendicular to the direction of its motion. Each order consisted of an arithmetical progression of fifty terms. The author observes, "this mode renders each order and series of experiments more comparable with each other, and enables us to arrange the results in tables, where the ratio, which any given resistance to one surface bears to the resistance to any other given surface within the limits of the experiments, may be found by simple inspection, without the trouble of calculation. But the greatest advantage of this arrangement is the facility which it affords of adapting the experiments to a scale, where the equal increments of the progression being considered as portions of the axis or absciss, and the resistances as the ordinates of an indefinite curve, each order of experiments becomes the object of a geometrical analysis; and it is evident, that if the equation or quadrature of these curves *can* be obtained, the law of resistance applicable to that particular case is at once discovered, and formulæ may then be deduced from it for every case of practice within the limit of that law."

The second class of experiments was made to find the ratio of the resistance to the velocity, the surface of the moving body and the angle of incidence being given. "The velocities in this class of experiments consisted of twenty terms, beginning with the velocity of one foot per second, and increasing, by the addition of one foot in each series, to the ultimate or greatest velocity of twenty feet per second, which being something more than thirteen miles and a half per hour, and exceeding the greatest velocities to which floating bodies are usually exposed in practice, seemed as great an extent as it was necessary to carry experiments of this kind to."

The third class of experiments was made to find the ratio of the resistance to the length of the body opposed to the fluid, the surface of the moving body, the angle of incidence, and the degree of the velocity being given. "In this class, the whole of the surfaces made use of in the preceding experiments come again in review, adapted to prismatic or cylindric bodies, increasing in length by small but equal portions, so as to form

an arithmetic progression of fifty terms, having in all the orders of this class, as in the preceding, unity for the first term, and also for the common difference. The first term, or unity, of every series in length equal to the diameter of its base, and the resistance of its base under every variation of area, angle, and velocity, having been previously ascertained by the preceding experiments, it is obvious that every increase or diminution of resistance now found must be occasioned solely by the difference of length of the opposed body."

The second set of experiments was made under various circumstances to ascertain the resistance a body experiences moving in a fluid, occasioned by the diminution of the pressure on the posterior surface of the body.

These experiments were conducted on the same principles as those of the French Academy of Sciences, the translation of the report of which has been given in this volume, but the bodies were on a much smaller scale. They possess however this merit, that they were made under a greater number of different circumstances, and must be considered as carrying forward the subject of the resistance of fluids by experiment, to cases not contained in that magnificent and most valuable course of experiments, worthy the nation and the great philosophers and mathematicians who conducted them.

Though Mr. Mackonochie did not publish the particular results of his experiments, he has however given us, in this prospectus, some remarks on the general results on some parts of the subject. Speaking on the relation of the resistance to the velocity, he says, that in small velocities he found the resistance varied very nearly as the squares of the velocities; but that, as the velocity increased, the resistance was augmented more rapidly, and that, with great velocities, the resistance exceeded even the cubes of the velocities.

On the results of the experiments to find the ratio of the resistance to the length of the body, he says, that he found that the resistances gradually diminished as the length increased to a certain extent and in a certain proportion, beyond which the resistance increased as the length of the body was augmented; so "that there is a certain ratio of the length to the area of the opposed surface, which gives the *minimum* of re-

sistance." He observes also, "that different areas require different proportions of length to obtain the *minimum* of resistance; and even the same area, when under different forms, requires different lengths."

This is a subject which is attended with great difficulty, and which it is particularly necessary to subject to experiment, as there is but little, unconnected with experiment, to guide us in abstract reasoning on it. In the present state of our acquaintance with the action of fluids, where so little is known, and so many points of consideration present themselves in this part of the subject, it is particularly desirable that the results of Mr. Mackonochie's experiments on this part of the subject should be known. The friction of bodies moving in fluids is immediately connected with this part of the subject. Various experiments have already been made on the friction of bodies moving in water, which might either be admitted, if considered sufficiently correct, or other experiments might be made, and its effects duly accounted for, in deducing results from this part of the subject of resistance of fluids, which might be applicable to naval architecture.

Mr. Mackonochie observes, "It is well known that a fluid, whether elastic or otherwise, in the common acceptation of the term, can rush into a vacuum with a determinate velocity only. If the velocity with which it moved were infinite, then any body moving in that fluid, with whatever velocity, would with respect to the fluid be in a constant state of equilibrium, and it would advance with the whole force of the impelling power, and be retarded only by the absolute resistance of the fluid medium. But matter, metaphorically speaking, is inert or sluggish, and requires *time* to move from one space to another. If, therefore, a solid body advance in a fluid with a greater velocity, than that fluid by the peculiar laws which govern its motion, can rush into the space left by the solid, in that case a rarefaction, more or less, according to the velocity of the moving body, will be formed behind it, and the equilibrium, which all fluids tend to preserve amongst their particles, will be destroyed."

Mr. Robins, in his investigations on Gunnery, did not consider that a body moving in air experienced any additional

resistance from a pressure of unbalanced elasticity, till the velocity of the body increased to 1100 or 1200 feet in a second, the velocity with which air would rush into a vacuum. Dr. Robison, in his valuable Essay on the Resistance of Fluids, showed that this increase of resistance existed whatever was the velocity of the body's motion, arising from the limited elasticity of the air. Speaking of the resistance a ship experiences moving in the water, he observes, "were the gravity of water infinite, while its inertia remains the same, the wave raised up at the prow of a ship would be instantly diffused over the whole ocean, and it would therefore be infinitely small, as also the depression behind the poop. But this wave requires time for its diffusion; and while it is not diffused it acts by hydrostatical pressure."

Mr. Mackonochie's object, from his experiments, was to endeavour, in connexion with the works of the best authors on Naval Architecture, "to reduce the forms of ships to some certain fixed principles, according to their respective destinations, whether of war, commerce, or intelligence." How far he succeeded, the prospectus does not inform us. If he attributed to the resistance of fluids too exclusive a share in this extensive subject, it is to be feared that his success was not very complete. The stability of a ship to enable her to carry sail, the quantity and disposition of the sail in relation to the mean direction of the fluid, the weatherly properties of a ship, and the ship's pitching and rolling, are subjects which require much greater consideration than he appears to have assigned to them.

It is frequently injurious to the improvement of Naval Architecture to found the hope of its advancement too exclusively on the necessity of having a correct theory of the resistance of fluids, however desirable this object may be. It is probable, that if part of the labour, which philosophers have bestowed on this subject, had been applied to the more certain and better known principles of design, this science would have advanced more rapidly than it has done.

It may be asked, what practical advantages have resulted to ship-building by the numerous experiments which philosophers have made to determine the resistance which bodies experience

moving in fluids; and rapidly and illegitimately assuming that ship-building has not been benefited by the results, the conclusion is unphilosophically assumed, that future experiments are therefore useless. It has however taught us, that the velocity of ships depends on the form of the after-part of the body as well as the fore-part. It has taught us, that while sharp bodies are less resisted in still water in a direct course, if the sharpness is given by great length, there is a maximum in this length beyond which the resistance is increased. It has given us some knowledge of facts, and it has given such an opening to the vast extent of circumstances connected with the subject of resistances, as to make us unwilling to draw hasty conclusions, to be sensible that there is but little developed, and to point out to us unexplored objects of investigation. When the results of past experiments shall have been fully examined, in connexion with Naval Architecture, future objects of inquiry will be suggested by the state of the subject in its progress, and other courses of experiments may be instituted, which may still carry on the inquiry; and who can say what patient and continued investigation may accomplish?

The second part of the subject was to consist of an inquiry into the laws of cohesion of fibrous solids, which he proposed to consider under three heads: "the anatomy and physiology of plants; the chemical analysis of the component parts; and, lastly, the resistance which they oppose to external forces, tending to disunite or separate their fibres. His principal object in the consideration of this subject, was to ascertain the causes of the greater durability of Indian teak than of English oak; and to be able to deduce from his experiments a method of rendering oak, by a very simple prosess, as durable as teak." His theory, which he founds on experiments as well as on reasoning, is, that the spontaneous decomposition of timber, which commences from the period at which it is felled, is caused by the oxygen it contains. Oak timber contains a considerable quantity of lignic acid, the oxygen of which, he considers, destroys the wood: teak timber contains less lignic acid than oak, but a much greater quantity of oily and resinous particles; by which he accounts for the greater durability of the teak.

The method which he proposes to increase the durability of oak timber, is, "to deprive the timber of the oxygen it contains, and to fill the interstices of the ligneous fibres, previously occupied by that gas, with some substance which may prevent its re-entrance;" and he considers oil to be a proper substance to produce this effect. He proposes the action of steam as well calculated not only to eject the oxygen gas from timber, but by its converting the fluids in the timber into a gaseous form, to eject them also. The author observes, that he had a steam chamber in use in the East Indies in 1803, in which the timber, while being rendered flexible for use, was saturated with teak oil.

The methods hitherto tried in this country, (see Knowles "On the Means of Preserving the British Navy,) do not render Mr. Mackonochie's plan the less worthy of trial. It appears too, *in principle*, the only method by which timber may be deprived of its chief inherent cause of its rapid decomposition, whatever substance may be found by experiment the best for saturation.

The advantage of saturating timber the author considers would be great in the preservation of the metallic fastenings, particularly of the iron. This part of his subject must be reserved for future consideration.

The third part of the subject is, an inquiry into the mechanical structure of fibrous solids. He observes, that this part of his work will consist of an inquiry into "the number, texture, arrangement, and disposition of the ligneous fibre in different kinds of wood; from whence an attempt will be made to deduce the laws of cohesion of these solids, as far as is dependent on their mechanical structure, with an endeavour to prove the causes of the different degrees of strength of different kinds of wood, as effected or produced by the various arrangement of their fibres." This inquiry was to embrace an extensive consideration of all the different operations of carpentry, such as scarphing, faying, tabling, coaking, morticing, dove-tailing, or otherwise jointing timber."

Mr. Mackonochie makes this bold assertion, that a ship "in a mechanical point of view, as a machine composed of wood and iron, is the feeblest, most inartificial, and unworkmanlike structure in the whole range of mechanics," and strongly re-

probates the present system of framing ships, which depends almost entirely on the fastenings for their connexion.

Though many improvements in the mechanical construction of ships have taken place since Mr. Mackonochie's death, it must be admitted that still very much remains to be done. The consideration of this part of the subject, with his observations on it, must however be deferred to a future opportunity.

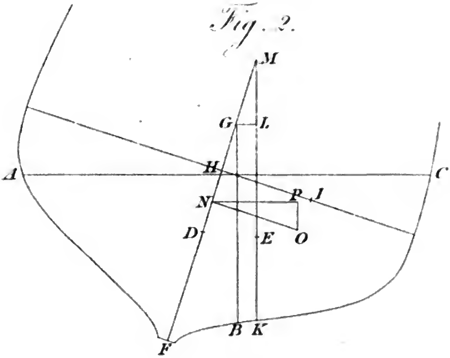
These few remarks on this prospectus will show the extensive view the author took of this science.

From the great interest which Naval Architecture has lately excited in this country, it is confidently to be hoped that this science will advance more rapidly than it has hitherto done. While the importance of the subject renders it an object of national policy, its magnitude requires national support and encouragement, to enable its branches to be properly investigated. The encouragement already given by the government to this science, has given an impulse to its advancement; and it is with the most loyal feelings and the liveliest hopes, that many deeply interested in the welfare of their country, look forward to the Naval Administration of his Royal Highness the Lord High Admiral. That his Royal Highness's administration may be attended with the most substantial benefits to all branches of the Naval Service—that the glory of the British flag may be still more resplendent—and that the most brilliant success may crown all his Royal Highness's exertions for his country's good, is the ardent desire of his Royal Highness's most devoted servants.

M.

END OF VOL. I.

Fig. 2.



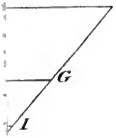
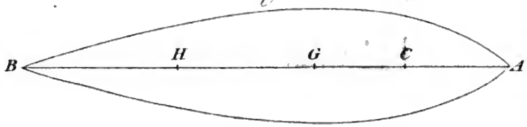


Fig. 7.



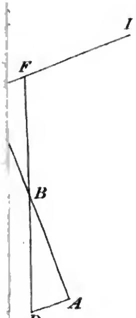
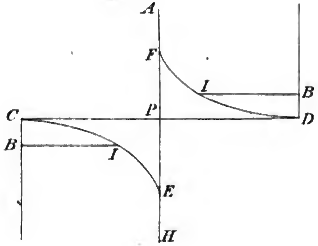
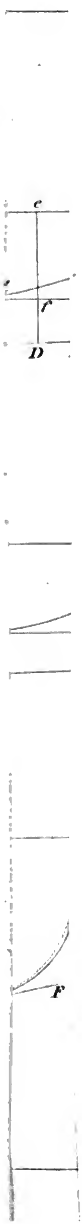
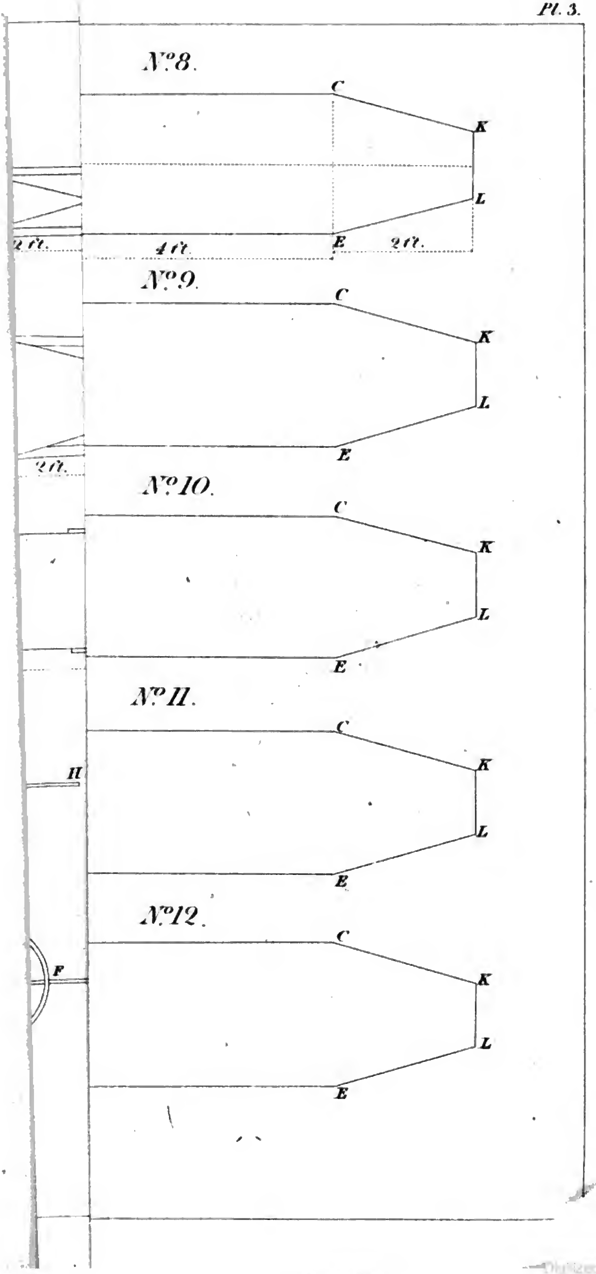


Fig. 6.




e
f
D
F


N.º 8.
C
K
L
E
2 ft.
4 ft.
2 ft.
N.º 9.
C
K
L
E
2 ft.
N.º 10.
C
K
L
E
N.º 11.
C
K
L
E
H
N.º 12.
C
K
L
E
F

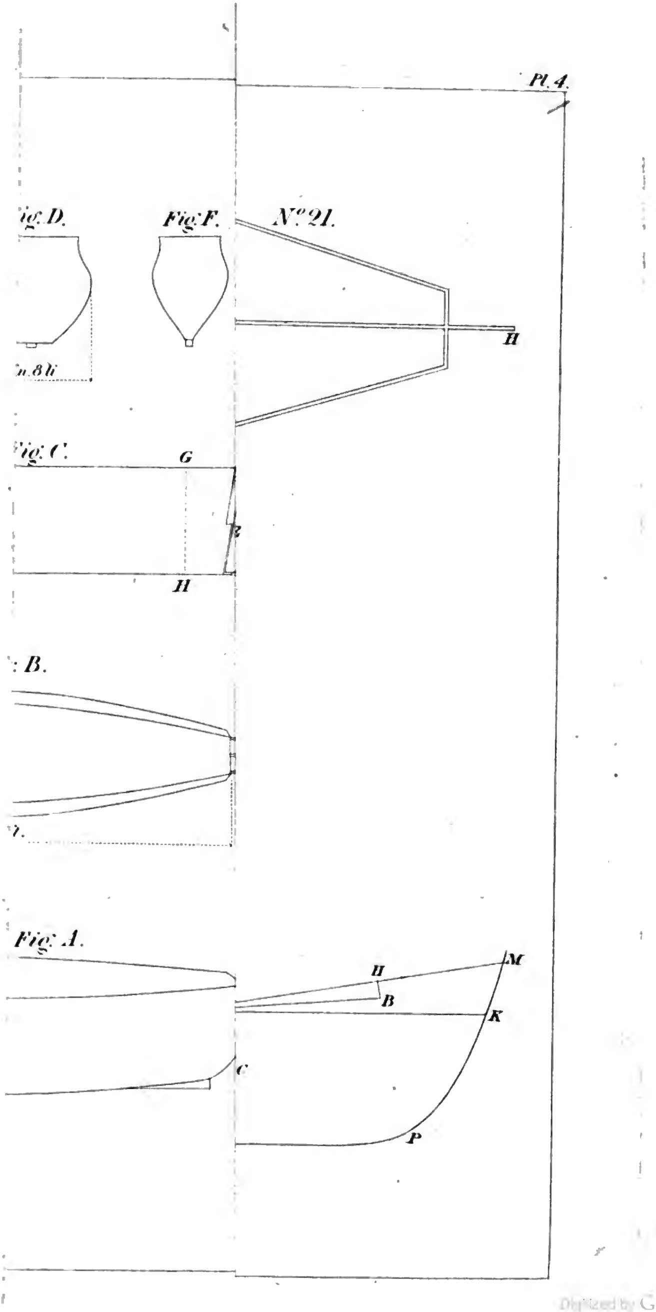
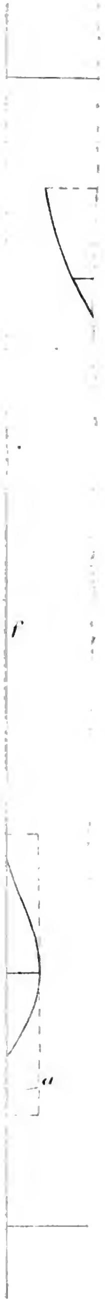


Fig. D.
Fig. F.
N° 21.
H
Fig. C.
G
H
B.
Fig. A.
H
B
M
K
C
P

5



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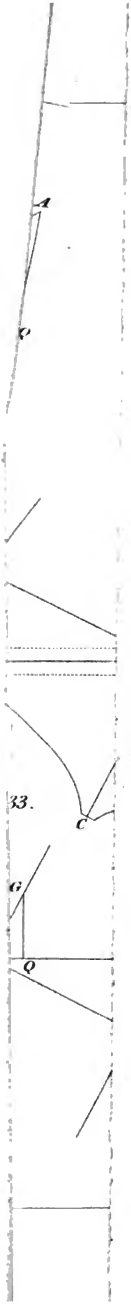


ig: 27.

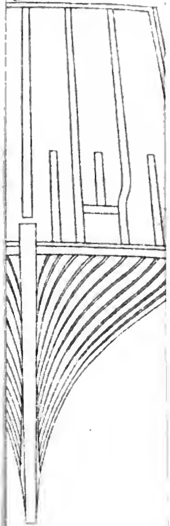
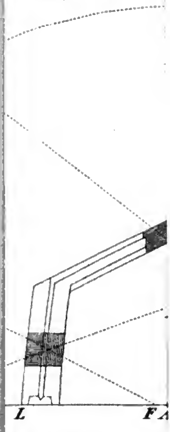


Fig: 30.



JW